The Power of Interest Rates.

The NOK/Euro Exchange Rate Under an Inflation Targeting Regime.

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Preface

I would like to thank my supervisor, Ragnar Nymoen, for his patience, help and useful feedback and comments. A special thanks to all my helpers who have contributed with proof reading and tips to all my minor mistakes.

I would also express my gratitude towards my close friends and family who have supported me and been able to cope with me for the past two years.

To all my fellow students: thanks for a great time!

All remaining inaccuracies and errors in this thesis are mine and mine alone.

Kaja K. Eckhoff

Oslo, May 2010

Summary

The goal of this thesis is to investigate how different factors have an impact on the exchange rate between Norwegian kroner and euro during the inflation targeting regime. The thesis uses a study by Bjørnstad and Jansen (2007) named "The NOK/euro exchange rate after inflation targeting: The interest rate rules" as both a starting - and reference point throughout the paper. Bjørnstad and Jansen investigate how a monetary regime shift affects the exchange rate in a small open economy. Their focus is on Norway and their transition from a fixed exchange rate targeting regime to an inflation targeting regime.

Several previous studies of exchange rate determination in an inflation targeting regime have been using data containing different monetary policy regimes. In this thesis it will be investigated if the same effects can be found using data containing an inflation targeting monetary regime only. The data used is a sub sample of the data sample made by Bjørnstad and Jansen, which solely contains inflation targeting monetary policy in the years from 2001 to 2009. It will be looked into how the Bjørnstad and Jansen model, and later a new model, works on the sub sample. How these models perform during the financial crisis in 2008 and 2009 is also a topic.

The last large change in Norwegian monetary policy came in March 2001, when Norway adopted an inflation target. The monetary exchange rate regime Norway has today is a result of economic evolution and several reforms of the monetary systems over the last 100 years. Norway has gone from a fixed exchange rate against a silver standard in the end of the 19th century, to floating exchange rate with an inflation target in the beginning of the 21st century. This transition has been influenced and dictated both by events happening in Norway and events happening with their trading partners. The development of the different Norwegian monetary regimes through history, as well as the events which made this happen, are briefly reviewed in the second section of this paper.

There is a huge amount of different economic theories on the subject on exchange rate determination. In an effort to limit the extent of this thesis, the only theory mentioned here is the portfolio theory on exchange rate determination. That being said, portfolio theory is not considered to be the only functioning theory. The portfolio theory is chosen due to the data

sample at hand and for its simplicity on deregulated exchange markets. A brief outline of a simple portfolio model is included in this paper.

There exist several empirical studies in the field of exchange rate determination. In this thesis a few of these studies are briefly discussed, among them the earlier mentioned study by Bjørnstad and Jansen. These empirical findings represent the results after trying to model exchange rate development on different monetary regimes. The model by Bjørnstad and Jansen has been replicated and its performance has been thoroughly explored on different sub samples. A quick out-of-sample forecasting competition between the model by Bjørnstad and Jansen and a Random Walk model has also been done. One finding is that the Bjørnstad and Jansen model experience great trouble when it comes to both explaining and forecasting the financial crisis.

The model by Bjørnstad and Jansen also contain some positive qualities that deserve to be investigated further. In the light of this, a new model on exchange rate determination under an inflation targeting regime is established. A sub sample of the data set by Bjørnstad and Jansen which only contain the years from 2001 to 2009 has been used. In this paper it is found that the major explanatory factors in exchange rate determination is the interest rate differential between Norway and Europe, and in specific the interest rate development in Norway.

The new model, in similarity with the Bjørnstad and Jansen model, do not predict the financial crises. Thus, the conclusion to this problem is that the events that determined the exchange rate during the financial crisis are exceptional circumstances, which disturb the relationship between the variables.

Contents

1 Introduction

In a globalized world, with trade between countries, exchange rates is a factor which attracts attention from governments, central banks and private investors. The choice of monetary policy regime will have an impact on the determination of the exchange rate and its development. Further, the exchange rate will affect both trade between countries and the viability of companies exposed to trade.

Floating exchange rates, which Norway has today, is usually determined by supply and demand of currencies in the foreign exchange market. The question is which factors decides supply and demand? Even though there are multiple economic theories on this subject, few of them have actually been proven to have empirical evidence. This is considered to be an economic puzzle.

The goal of this thesis is to investigate how different factors have an impact on the exchange rate between Norwegian kroner and euro. A study by Bjørnstad and Jansen (2007) is used as both a starting - and reference point throughout the paper. Bjørnstad and Jansen investigate how a monetary regime shift affects the exchange rate in a small open economy.

Previous studies of exchange rate determination in Norway during an inflation targeting regime have been using data containing different monetary policy regimes. This paper investigates whether their results are in place when using data only containing an inflation targeting monetary regime. The focus in this study is on the NOK/euro exchange rate. Norway has only had an inflation target since 2001, which makes the dataset, containing quarterly data from this period, somewhat limited. Anyhow, a very important virtue of the model made on this data, is that none of the misspecification tests are significant, such that inference about the variables based on the t-values and F-statistics can be made.

When the financial crisis exploded in 2008, a critique against the economists was that they had not seen it coming. This paper also investigates whether the empirical models were able to predict or explain the events happening to the exchange rates during this period.

The paper is organized as follows: In chapter 2, a quick summary of the development of the different Norwegian monetary regimes through history are given. Chapter 3 gives a brief outline of a simple portfolio model, which is used as theoretical base in this paper. Some empirical results that both support and contradict the theory are presented in chapter 4. These empirical findings represent the results after trying to model exchange rate development on different monetary regimes. For the time being, none of these have tried to focus only on inflation targeting monetary regimes. As a result of this, a model solely based on data from an inflation targeting regime is made in chapter 5. This chapter also investigates how this model among others explains the financial crisis which hit the world financial markets in 2008 and 2009. Chapter 6 concludes.

All the econometric programming and analysis, including tables and figures, have been done using the econometric software OxMetrics 6 and PcGive 13.

2 Monetary Regimes in Norway since the 19th Century.

The monetary exchange rate regime that Norway has today is the result of economic evolution and several reforms of the monetary systems over the last 100 years. A short summary of the development since the end of the 19th century is included as a background to the analytical parts of this thesis.

From the 1850's Norway had a silver standard, which later was changed for a gold standard in 1873. The silver and gold standard required the Norwegian central bank to exchange the Kroner against gold at an official price. This system was in operation until the start of the First World War in August 1914, when Norges Bank (The Norwegian central bank) gave up the required exchange against gold. There was a rush on banks as people tried to exchange money for gold. Because of this massive demand for gold exchange, the central bank could no longer honor its obligations and were forced to give up the gold standard. Formally, the Norwegian Krone was still fixed to gold, but the price of the Krone against foreign currency was no longer dictated by the value of gold. According to Mestad (2002), we characterize the regime from 1914 and forward as a floating exchange regime.

In the 1920's Norway tried to get back to the gold standard at the same exchange rate value as before the war (the so called "paripolitikk"). In a determined attempt to reach this goal, Norway ran deflationary politics to get the value of the krone up. This policy was controversial and led to political debates and criticism from monetary circles. Despite skepticism, the revaluation policy was pushed through, and in April 1928 Norway was back on the gold standard (Mestad (2000)).

The big crack on the New York stock exchange in the autumn of 1929 was the beginning of the Great Depression in the 1930s. This caused a financial crisis not only in the US, but also in Germany, England and other European countries. In September 1931 England had to abandon its gold standard, and only a few days later Norway did the same. This resulted in a two year period with floating exchange rates in Norway.

The Norwegian government fixed the Krone to the British pound at a rate of 19.90 Kroner per pound in august 1933, in an effort to achieve price stability. At the same time, the central bank obtained tight control over all foreign currency transactions. When the Second World War began in 1939, Norway switched the peg to the US Dollar, which was still connected to the gold (Mestad (2002)). During the war special actions were set into place and Norway experienced strict capital controls, cf. (Klovland (2004)).

After the Second World War, the Norwegian exchange rate was mainly decided through international agreements. The Bretton Woods agreement, made in 1944, was a new international system of fixed exchange rates. Countries pegged their currency to the US Dollar, and the Dollar was convertible to gold at a fixed price. The US Dollar was chosen because of USA's leading role in the world economy, and American monetary policy became a benchmark for interest rate and inflation development for the rest of the countries in the agreement. The Norwegian Krone was set to a fixed rate of 4.03 Kroner/dollar and 20 kroner/British pound. Maximal deviation from the fixed rate was one percent[1]. However, the first devaluation happened already in 1949. England was no longer able to hold the fixed rate to the dollar and a devaluation of 30.5% took place. Norway devaluated shortly after (Mestad (2002)).

The agreement worked well in the 1950s and 1960s. In the end of the 1960's the US had trouble holding the dollar at the fixed price, because of high inflation and big deficits in their current account due to the Vietnam War. This resulted in a massive wave of speculation and the system broke down in 1971, (Sørensen and Whitta-Jacobsen (2005, p.803), Norges bank (2004)).

After the breakdown of the Bretton woods agreement Norway had floating exchange rates in a short period of 5 months. This ended in December 1971 when Norway entered the Smithsonian agreement, which was the descendant of the Bretton woods system. The gold-dollar relationship was removed and all the member countries agreed upon bilateral exchange rates with a fluctuation band of ±2.25 per cent. The European Economic Community made their own agreement in addition, with half the fluctuation band in the Smithsonian agreement. The Norwegian authorities, who thought the wide fluctuation band in the Smithsonian agreement made the currency connections too unstable, joined the EEC agreement in 1972 (see Mestad 2002). The system was called "the snake in the tunnel" because of the smaller fluctuation band inside the wider Smithsonian band.

[1] http://www.norges-bank.no/templates/article____12107.aspx.

The Smithsonian agreement broke down in 1973, since neither England nor the US was able to keep the exchange rates that they had agreed upon. As a result of the breakdown, the largest currencies (Dollar, Pound, Yen and the German mark) went floating. The rest of the European countries in the agreement kept their bilateral rates, fixed to the currencies in the snake and floating to the ones outside; cf. Norges bank (2004).

After several devaluations of the Kroner, Norway left the agreement in December 1978 and introduced a currency basket, because the currency snake developed to become a part of the European Monetary System. The currency basket was trade weighted, according to the size of each country's trade. Shifting of the weights in the currency basket resulted in multiple effective devaluations during this period, (Mestad (2002)).

In 1990 the Krone was fixed against the European currency unit (ECU). The ECU was a basket of the currencies in the European Community, and it was only used as an account unit until it was replaced by the Euro in 1999[2]. The change of the peg was an effort by the Norwegian government to get a closer connection to the European monetary system, which was established in 1979. The Norwegian interest rate was tightly connected to the European interest rate, due to high capital mobility and the fixed exchange rate (see chapter 3.4).

When the European currency crisis hit in 1992, the European interest rate, and therefore also the Norwegian interest rate, increased dramatically. There was a widespread belief among investors in the market for foreign exchange that the interest rate was at a higher level than the Norwegian economy could cope with. This led to massive speculations against the Norwegian Krone. The Norwegian Central Bank fought against the speculations with even higher interest rate in an effort to stop the speculations. At December 10th 1992 the central abandoned the fixed exchange rate (see Gjedrem (1999)) and the Krone was free to float. In a message to the International Monetary Fund, Norges Bank wrote:

> "When the krone was linked to the ECU in the autumn of 1990, the central bank emphasized that in so doing we pegged the value of the Norwegian krone to the currencies of a group of countries whose long-term objective is to stabilize prices. Circumstances beyond our control have forced on Norwegian authorities the decision

[2] http://www.europaveien.no/index.php?option=com_content&task=view&id=267&Itemid=191

> to allow the krone to float. However, the main objective of monetary and exchange policy is still to maintain price and cost growth at the prevailing level" [3]

Other European countries experienced the same, and let their currency float (e.g. Swedish Krone, British pound and Italian Lire) during 1992 (See chapter 3.4.2).

The floating exchange rate regime was continued and the international value of the Krone was based on the exchange rates in the currency market. In 1994, the goal of monetary policy was to contribute to low and stable increases in prices and costs. To achieve this, a target of a stable exchange rate against the European currencies (the ECU and later the EURO) was implemented. The central bank could intervene in the currency market to keep the Norwegian currency stable and Norway thus had a "dirty" float regime during this period (Bjørnstad and Jansen (2007))

The exchange rate was fairly stable until the triple crisis hit in 1998 (the Asian, Russian and South American) and the Norwegian Krone experienced big fluctuations and deflationary pressure (cf Bjørnstad and Jansen (2007)). As a result, the Norwegian central bank had to use the interest rate actively. The sight deposit rate was as high as 10% in 1998. This reduced the pressure, and in 1999 the interest rates was lowered to more normal levels.

In March 2001, a new target in the floating exchange rate regime was finally introduced. The monetary policy now became directed towards low and stable inflation. The goal was stable inflation on 2.5 percent over time. To achieve this, the interest rate should be used. The exchange rate could fluctuate according to the supply and demand in the currency market and it was free to float without interventions from the central bank.

From May 2000 to January 2003, the Krone appreciated considerably. Many reasons for this have been mentioned in the literature, but the dominating ones are increased interest rates relative to other countries, increased oil price, huge surpluses on the current account and the Krones status as a safe haven during unrest in the Middle-East, (Naug (2003), Bjørnstad and Jansen (2007), NOU (2003, no13)). All these reasons will be investigated in the following chapters. After a correction from 2003 to 2005, the exchange rate has been floating around 8-8.25 Kroner per euro until the financial crisis hit in 2008 and the Krone depreciated sharply.

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[3] Rundskriv 1/12 jan. 1993 (from Mestad 2002)

Figure 1 shows how the incidences in the history have affected the exchange rate. All major happenings have had an impact on the exchange rate, and led to either appreciation or depreciation.

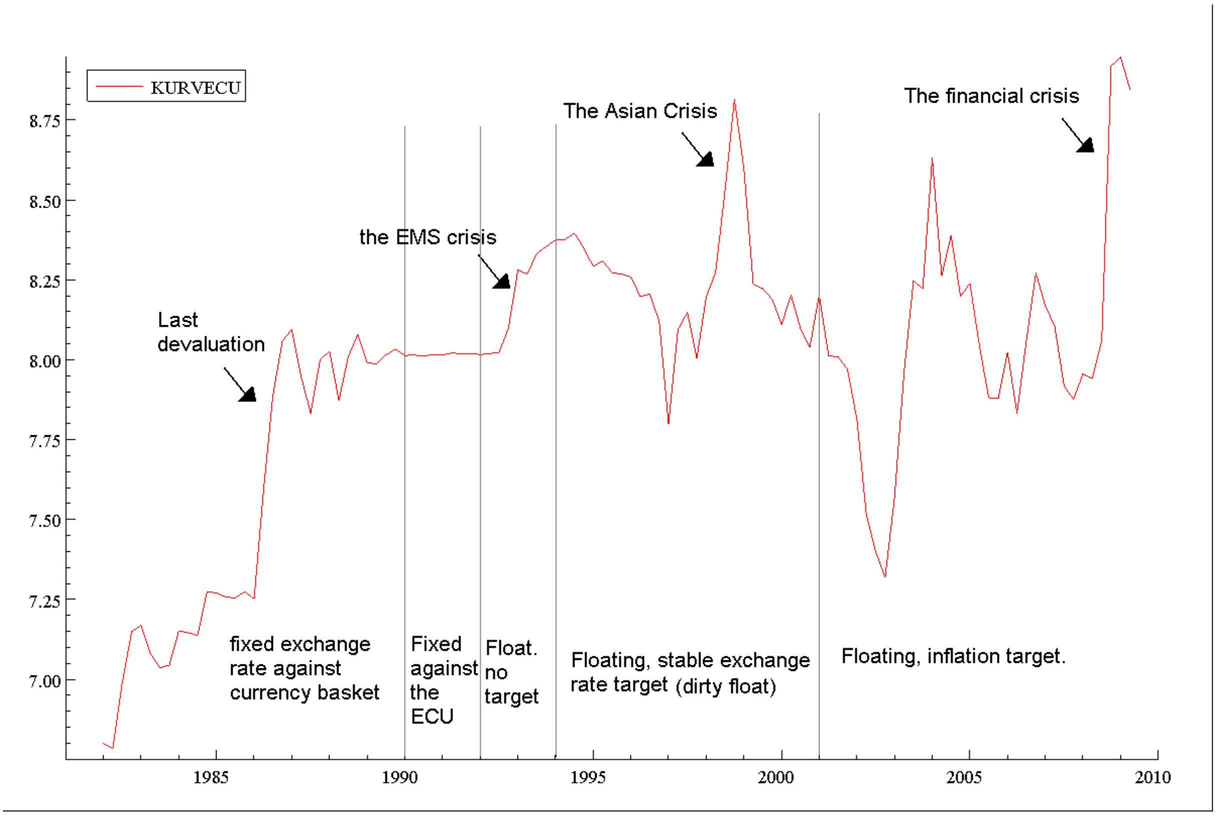

Figure 1 NOK/Euro exchange rate after 1983[4]

After the inflation target in 2001, the interest rate has experienced more variation than usual. This is not uncommon because of the new floating exchange regime. The core of this thesis is to investigate what may lie behind this variation.

[4] Kilde: http://www.regjeringen.no/nb/dep/fin/dok/nouer/2003/nou-2003-13/7.html?id=370327, Holden 2002(http://folk.uio.no/sholden/Norske-valutakursregimer.doc), dataset.

3 Theoretical Framework: A Simple Portfolio Model

The portfolio model is a dynamic model of exchange rate determination. The equilibrium in the model is determined by current account balance between the sectors. The sectors are home and foreign private investors, who want to differentiate their asset portfolios, and the central bank.

3.1 The Market

The exchange rate is determined by supply and demand in the foreign exchange market. The supply for foreign currency is determined by the net supply of foreign currency by the domestic and foreign general public. The demand for foreign exchange is determined by the central bank. The public acts as price takers since their transactions are usually too small to affect the price. The central bank can make large interventions in the foreign exchange market, and thus, they can be large enough to influence the price on foreign exchange.

In the following I use the Norwegian Krone (NOK) as the domestic currency and Euro as the foreign currency. The exchange rate is the price of one unit of Euro in Norwegian Kroner.

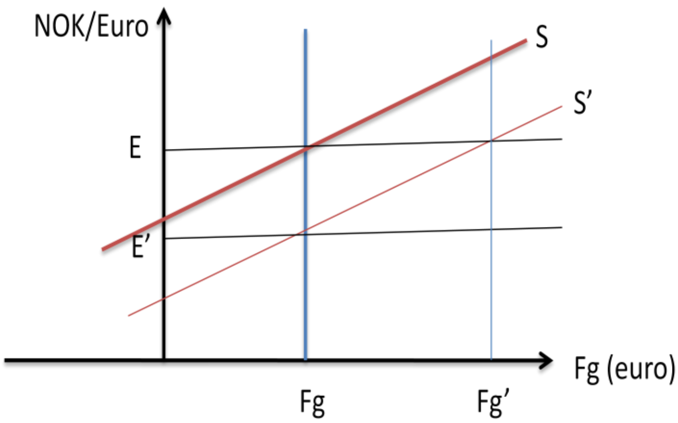

Figure 2 , Supply and demand in the foreign exchange market

In a fixed exchange rate regime, the exchange rate is predetermined, and thus exogenous, at a fixed level E. This implies that the central bank is committed to exchange the NOK for Euro at a given rate. If the supply of foreign currency for some reason should increase (S'), the central bank will have to buy the excess supply and increase its foreign exchange reserves ($F_g^{'}$) in an effort to keep the exchange rate at the fixed rate.

In a credible floating exchange rate regime, the central bank does not take any action if the supply of foreign currency should increase. The result of an increased supply of foreign currency is an appreciation of the NOK to a new level ($E^{'}$).

3.2 The Building Blocks of the Portfolio Choice Model.

I follow Rødseth (2009, Ch 1) and assume that the foreign exchange marked consists of three different sectors, which all can have both euro and NOK assets. The sectors are the government, which includes the central bank, the private and the foreign sector. All sectors can either borrow or lend in both currencies. One of the assumptions of the portfolio model is that it compares a small economy to the world, where the world is simplified to one country. In my example Norway is the small open economy and Europe is the other. It is important to notice that the net demands for all the sectors summarize to zero. The domestic public debts have to be equal the government and foreign claims, or the other way around.

Table 1[5], Net financial assets, by sector

Assets	Govern.	Private	Foreign	Total
Kroner	B_g	B_P	B^*	0
Euros	F_g	F_P	F^*	0
Total	$B_g + EF_g$	$B_P + EF_P$	$B^* + EF^*$	0

B_i = Net kroner assets of sector *i*, *i*= *p*, *b*,*
F_i = Net euro assets of sector *i*
F_g = Central Banks foreign exchange reserves or Government foreign currency debt

[5] Table 1,1 in Rødseth 2000. Rødseth uses Dollars as the foreign currency, while I use Euro.

The private domestic and foreign market participants will be interested in investing where the expected return on their investments is highest. The rate of return for domestic residents on NOK assets is the interest rate i. The rate of return on their foreign assets is $i^* + e$, where e is the rate of depreciation[6]. The investors get an extra return on their euro investment if the euro increases in value relative to the NOK , that is the NOK depreciates. If $i < i^* + e$, the highest returns are given on euro investments, and opposite if $i > i^* + e$. If $i > i^* + e$, you may gain by lending money in Europe and invest in NOK. However, no one knows exactly what the rate of depreciation will be. Instead investors have to base their decision on the expected rate of depreciation (e_e).

If there does not exist any trade barriers on international capital movements (e.g. taxes, transaction costs), all investors have the same expectations and base their decisions only on expected returns, then we have perfect capital mobility between currencies. In this case, if $i < i^* + e_e$, everybody wants to borrow NOK and invest in euro, meaning that nobody wants to buy NOK. The only way to ensure both borrowing and lending in both currencies is if

$$i = i^* + e_e$$

This condition is called the uncovered interest rate parity (UIP), and it is the cornerstone parity condition for foreign exchange market efficiency. It assumes that the foreign exchange market participants are endowed with rational expectations and are risk neutral (Sarno 2005). The UIP condition is a long run parity condition and has to hold under perfect capital mobility.

Usually the conditions for perfect capital mobility are too strong, and we then have what is called imperfect capital mobility. This means that investors may have both currencies in their portfolio, even though the UIP condition does not hold. According to Rødseth (2000, p.16) there are four main reasons why perfect capital mobility can be hard to achieve.

- *Exchange rate risk and risk aversion.* Risk averse investors may be willing to give up some of the expected returns in order to reduce the risk because of the uncertain depreciation rate. In this case, the investors will keep some of their wealth in risk free NOK assets and some in euro.

[6] e= Ė/E, where a dot over the variable is its derivative with respect to time (Rødseth 2000).

- *Differing expectations.* Because of the uncertainty about the rate of depreciation, people will have different expectations about the returns on the investments in foreign currencies. This implies that some will believe that NOK investments will give highest returns and vice versa. Furthermore, it gives people a possibility to lend and borrow from each other.

- *Transaction costs and liquidity.* Changing money comes with a cost. Fees for exchange may result in less currency transactions and people withdrawing from the market. People also need money for transaction purposes, which means that they will hold money, even though the expected returns may be higher somewhere else.

- *Exchange controls.* The government may have regulation on the supply of foreign exchange currency. There are several ways to regulate this, by quantitative limits on the investments, prohibit certain groups from the market or other ways.

Under imperfect capital mobility, where the foreign exchange market participants for instance are risk averse, the UIP condition may include a risk premium (r). This is because agents demand a higher rate of return than the interest rate differential in return of holding currencies considered to be risky, see Sarno(2005) and Alendal (2010). The risk premium is defined as:

$$r = i - i^* - e_e \quad \text{or} \quad i = r + i^* + e_e$$

The risk premium is the difference between the expected return on NOK assets and expected return on euro assets. Compared to euro, NOK is considered being a risky asset. Thus, the expected return on NOK has to be *r* units higher than the expected return on foreign currency ($i^* + e_e$) for investors to invest in NOK. The higher the risk premium, the more the investors are willing to invest in NOK. Notice that when the risk premium is zero the risk premium is reduced to the UIP condition ($i = i^* + e_e$).

The domestic investors want to divide their real wealth on domestic and foreign assets. Initial assets has a subscript 0.

$$W_p = \frac{B_{p0} + EF_{p0}}{P}$$

A main assumption of the model is that the demand for foreign asset investment is decided by the initial wealth and the risk premium.

$$\frac{EF_P}{p} = f(r, W_p)$$

The assumptions about the derivatives of the f-function are important: The higher the risk premium on the domestic currency, the more investors will shift the portfolio from foreign to domestic currency ($f_r < 0$) and an increase in wealth will be invested in both currencies ($0 < f_W < 1$) (Rødseth (2000)).

The domestic asset investment demand is decided by the rest of the wealth, after the foreign investments are subtracted. The excess wealth, which is not used on foreign investments, is invested at home.

$$\frac{B_p}{P} = W_p - f(r, W_p)$$

The same principles apply to the foreign investors. Note that the mirror image applies to foreigners, NOK assets are the foreign assets, while euro assets are the domestic assets.

Wealth is divided between home and foreign assets[7].

$$W^* = \frac{\frac{B_0^*}{E} + F_0^*}{P^*}$$

The demand for foreign assets (NOK assets) depends on the wealth and the risk premium.

$$\frac{B^*}{EP^*} = b(r, W^*)$$

The rest of their wealth is used on domestic assets (euro assets)

$$\frac{F^*}{P^*} = W^* - b(r, W^*)$$

$$b_r > 0, \qquad 0 < b_{W^*} < 1$$

[7] To avoid confusion in the rest of the thesis, a different type of subscript is used compared to Rødseth (2000).

The assumptions on the derivative of the b-function are the mirror image of the domestic f-function. The higher the risk premium on the foreign currency (on NOK), the more foreign investors will shift their portfolio from euro assets to NOK assets ($b_r > 0$). An increase in wealth will be invested in both currencies ($0 < b_{W^*} < 1$).

The degree of diversification in the portfolio depends on the investor's degree of risk aversion. A highly risk averse investor will demand a higher risk premium on risky assets than less risk averse investors. In this model the degree of risk aversion will be reflected by the properties of the b-and f-function[8], in particular the derivatives with respect to the risk premium. I assume that both the domestic and foreign investors have the same degree of risk aversion.

3.3 The Model[9].

The portfolio model of the market for foreign exchange is a system of equations which is made up by the relationship in section 3.2, as well as assumptions about the exogeniety or endogeniety of for example the nominal exchange rate. This implies that the different ways of "determining the model" corresponds to different monetary policy regimes.

A simple portfolio model consists of the following seven equations:

1) $W_p = \frac{B_{p0} + EF_{p0}}{P}$

2) $W^* = \frac{\frac{B_0^*}{E} + F_0^*}{P^*}$

3) $r = i - i^* - e_e$

4) $e_e = e_e(E)$

[8] For more on different forms of b- and f-functions, see Rødseth (2000, chapter 2)

[9] This is similar to equation 1.11 to 1.17 in Rødseth (2000, ch 1.4). The following builds directly on chapter 1 in Rødseth (2000).

5) $\frac{EF_P}{P} = f\left(r, W_p\right)$

6) $\frac{F^*}{P^*} = W^* - b(r, W^*)$

7) $F_g + F_p + F^* = 0$

Equations 1 and 2 define the financial wealth as the value of initial stocks. Equation 3 is the risk premium. Equation 4 defines the expected depreciation and how it depends on today's exchange rate. Equation 5 and 6 are the demand functions for foreign currency. Equation 7 is the equilibrium condition for the foreign exchange market. (Rødseth 2000)

In this model there are seven endogenous variables; private wealth W_p, foreign wealth W^*, the private sectors euro assets F_p, foreign euro assets F^*, the risk premium r and the expected depreciation rate e_e. Under a fixed exchange regime the foreign exchange reserves F_g are also endogenous, while under a floating exchange regime the exchange rate E is endogenous. Under a float F_g are kept exogenous, while E is exogenous during a fixed regime. The price levels (P and P^*) and interest rates ($i^*$and i) are exogenous in both regimes. In addition, B_{p0}, F_{p0}, B_0^* and F_0^* are predetermined.

Two additional assumptions of the model are that everybody has assets in both currencies in the initial period, and that not all capital gains are invested in foreign currency.

3.3.1 The Supply of Foreign Exchange

From equation 7 we see that supply and demand of foreign currency has to sum up to zero. The demand from the central bank (F_g) has to equal the supply ($F_p + F^* = F^S = F_g$) of foreign currency. If we first insert equation 7 into equation 5 and the result into equation 6, and later insert equation 1, 2, 3 and 4 we get the supply of foreign currency[10].

8) $F^S(E, i - i^*) = -\frac{P}{E} f\left(i - i^* - e_e(E), \frac{B_{p0} + EF_{p0}}{P}\right) - P^*[\frac{\frac{B_0^*}{E} + F_0^*}{P^*} - b(i - i^* - e_e(E), \frac{\frac{B_0^*}{E} + F_0^*}{P^*})]$

The supply of foreign currency depends mostly on two factors: the interest rate differential and the exchange rate.

[10]The relevant calculations are found in "Attachment B"

The exchange rate enters the equation both through the expected depreciation and through the value of the existing stocks. Therefore, the exchange rate has two effects on the supply: a portfolio composition effect and an expectations effect. This can be seen by differentiating the supply function with respect to the exchange rate and find the slope of the supply curve.

$$9)\quad \frac{\partial F^s}{\partial E} = \frac{P}{E^2}\left[(1 - b_{W^*})\frac{B_0^*}{P} + \left(1 - f_{W_p}\right)\frac{EF_{p0}}{P}\right] - \frac{P}{E}e_e^{'}(\frac{EP^*}{P}b_r - f_r)$$

The effect on the supply curve of an increase in the exchange rate is positive only if a set of sufficient conditions are satisfied. These are $F_{p0} > 0,\ \ B_0^* > 0,\ \ f_W < 0,\ \ \ b_{W^*} < 0, e_e^{'} < 0.$ The derivatives implies that the private domestic sector has foreign asset holdings initially, that foreigners have NOK assets, a wealth increase will be used on both home and foreign assets, and that the expectations are regressive (more on regressive expectations below). If all this is satisfies, then the supply curve is increasing (more on this discussion see Rødseth (2000, p.21).

The exchange rate effect on supply can be written more compactly as

$$\frac{\partial F^s}{\partial E} = \frac{P}{E^2}\gamma - \frac{P}{E}e_e^{'}\mu$$

where

$$\gamma = (1 - b_{W^*})\frac{B_0^*}{P} + \left(1 - f_{W_p}\right)\frac{EF_{p0}}{P}\ \text{, and}\ \mu = \frac{EP^*}{P}b_r - f_r. \qquad (b_r > 0, f_r < 0)$$

γ is called the portfolio composition effect. When the exchange rate increases, all foreign assets will increase in value relative to domestic currency assets. The effect will change the value distribution of each sectors portfolio, and as a result they will rebalance their portfolios.

The expectations effect is represented by -μ$e_e^{'}$. The degree of capital mobility is measured by μ. An increase in the degree of capital mobility will lead to bigger changes in the supply of foreign currency after interest rate changes, than in the case of a lower degree of capital mobility. High capital mobility will result in a flatter foreign currency supply curve relative to low capital mobility; see Figure 3. Under perfect capital mobility the supply curve will be completely horizontal. Another implication worth noticing is that changes in the central banks foreign currency fund will have a smaller impact on the exchange rate when capital mobility is high than when it is low. If capital mobility is perfect and the supply curve is horizontal, interventions from the central bank will have no effect on the exchange rate. However, the simple portfolio model breaks down with perfect capital mobility. The risk premium equation is reduced to the UIP condition, and the demand equations for foreign exchange are not well defined. For completeness, we note therefore that in the case of perfect capital mobility, the system of equations (1)-(7) can be replaced by a single equation:

10) $i = i^{*} - e_e(E)$

Since r = 0 by definition.

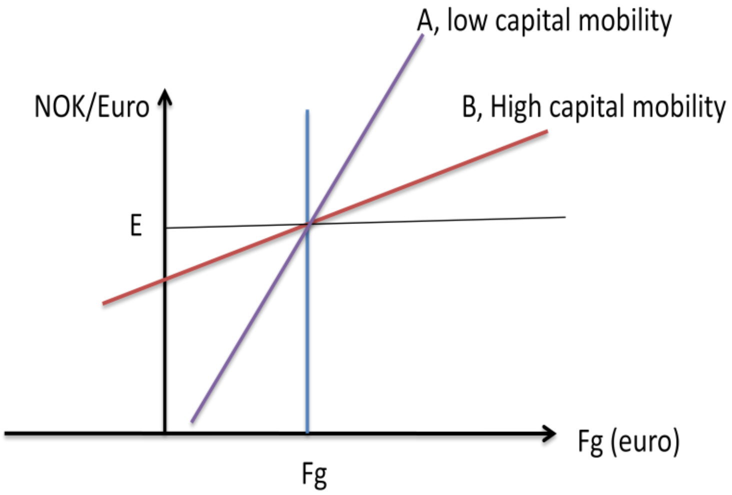

Figure 3 supply curves with different capital mobility

Depreciation may change expectations about future exchange rate changes (e_e). This will change the risk premium, which has an impact on foreign currency demand. The sign on the expectations effect depends on the sign of the expectations. I will use regressive expectations ($e_e^{'} < 0$) as a reference case, which means that depreciation now lowers the expected future depreciation. We also have extrapolative expectations ($e_e^{'} > 0$), where a depreciation now increases expected future depreciation, and constant expectations ($e_e^{'} = 0$) where a depreciation now has no effect on expected future depreciations (Rødseth 2000). Regressive expectation has some empirical evidence, and the only way the expectations effect is positive is with regressive expectations ($\mu e_e^{'} < 0$).

The effect of an interest rate change on the foreign currency supply can be found by differentiating the supply with respect to the interest rate.

$$11)\quad \frac{\partial F_g}{\partial i} = -\frac{P}{E} f_r + P^* b_r = \frac{P}{E}\left[-f_r + \frac{EP^*}{P} b_r\right] = \frac{P}{E}\mu > 0$$

Where μ still is the degree of capital mobility and is positive.

We can see that this effect is positive, the supply of foreign currency increases when the domestic interest rate increases. When the domestic interest rate increases, investors want to sell some of their euro holdings and invest in NOK. This will increase the supply of foreign currency, as in Figure 2. The size of the effect of the increased supply depends on the degree of capital mobility between the two currencies.

3.4 Fixed Exchange Rates

Generally, the central bank has two instruments that affect the supply of foreign currency. It can either use the interest rate or the foreign currency reserves. When the exchange rate is fixed, the central bank looses one of its instruments in effort to keep the exchange rate fixed.

The central bank can determine the level of the risk premium with the interest rate, to get the domestic money market in equilibrium through endogenous money supply. The risk premium is one of the factors which influence the behavior of the suppliers of foreign currency. If the central bank sets the domestic interest rate lower than the interest rate abroad, it will decrease the risk premium. Such a reduction in the risk premium will in turn reduce the supply of foreign currency and give an upwards pressure on the exchange rate, see Figure 2. To keep the exchange rate stable the central bank will have to use its foreign currency reserves to buy NOK. These changes in the foreign currency reserves can be large if capital mobility is high. As a worst case scenario, the central bank can run out of foreign currency. The central bank can borrow foreign currency to buy NOK. Still, there will be limits on how much the central bank can borrow in the short run. Irrespective of this, the central bank ends up as a borrower in the market with the highest expected return and a lender in the market with lowest. Thus, the result might be rather costly in the long run. Consequently, the easiest thing for the central bank to do is to keep the interest rate tightly connected to the foreign interest rate in order to keep the risk premium stable.

3.4.1 Speculation against Fixed Exchange Rate Regimes.

Fixed exchange rate regimes can be vulnerable against currency speculations, even though there may not be any reason for devaluation in the real economy. The reason for this vulnerability is the possibility of speculation in enormous amounts against a currency with low risk, called “one-way bets”. “One way bets” has the opportunity to score huge gains at the risk of loosing very little. This is only possible if all the market participants agree about the way the currency should be moving, and there has to be someone to bet against, which is usually the central bank, (see Holden (2006)[11]).

When financial investors believe that some currency such as the NOK may soon be devaluated, they have got an incentive to borrow NOK in the bank, invest in for example euro, and exchange it back to NOK after an eventual devaluation. If the NOK has been devaluated it is possible to have huge gains. However, if the NOK has not, it has only led to a small transaction cost; see Sørensen and Whitta-Jacobsen (2005, p. 757). In the portfolio model, this expected devaluation will be the same as an increase in the expected depreciation rate e_e in the risk premium equation. An increased e_e will result in a decreased risk premium if interest rates were kept constant. A decrease in the risk premium may lead investors to shift their portfolio away from the domestic currency to the foreign currency. This will lead to a negative supply shock in figure 2.

The central bank has two ways to react:

1) It can sell foreign currency and buy domestic in an effort to keep the exchange rate stable. Without huge foreign currency reserves, there may be a risk of the central bank not being able to keep the exchange rate at the fixed level, and a devaluation may be the result.

2) It can increase the domestic interest level in the same amount as the increase in e_e. This will keep the risk premium unchanged. An unchanged risk premium will not give the

[11] http://folk.uio.no/sholden/E1310/ECON1310-H09-sh.html

investors any excuse to shift their portfolios. A higher interest rate can in addition fight of speculation because it will make it more expensive to borrow NOK, see Rødseth (2000). Unfortunately, the increase in the interest rate needed to compensate for the change in the expected depreciation rate can be huge. During the EMS currency crisis in 1992, Sweden had to increase their overnight lending rate to 500 per cent to fight off speculations against the Swedish Krone (Sørensen and Whitta-Jacobsen (2005)). Very high interest rates over long periods of time can seriously harm the economy and history shows that the central bank will often give up their peg rather than inflict huge costs on the economy. When there are high capital mobility and no exchange controls, it can be very hard for a small country acting alone to keep their currency fixed unless the central bank has credibility. For the central bank to keep of speculative pressure, the public needs to be fairly confident that their currency is not being devaluated.

3.4.2 The EMS Crisis in 1992-93

The European Monetary System was introduced in 1979 and the countries in the European Union had to commit to keep their bilateral exchange rates fluctuating only ±2.5% around the fixed exchange rate parities. Germany participated in the system, but would not let go of their monetary policy which was directed towards low and stable inflation. In this way, the rest of the EMS countries pegged their values to the German mark and had to coordinate their interest rate according to the German interest rate. As a result, all the other EMS countries experienced a lower and more stable inflation rate. The system worked well all the way to the 1990s. Even Sweden, Norway and Finland decided to peg their currencies to the ECU in 1990. However, the reunification of East and West Germany in late 1990 led to huge fiscal expansions, and the Bundesbank raised the interest rate to obstruct a boost in the inflation rate. The rest of the EMS had to increase their interest rates accordingly and entered a recession which deepened as Germany kept its interest rate up.

In 1992 the international financial market participants started to doubt if the other EMS countries would stick to their peg, or devaluate their currency against the German mark in an effort to escape the recessions. In September 1992 violent speculative attacks against most of the EMU member countries started. Within a few days, Finland, Italy and the UK had to drop out of the EMS system and allow for floating currencies. Even though higher interest rates were used to fight of the speculation, Sweden moved to floating exchange rates in November, with Norway joining them in December. In the summer of 1993 practically all the EMS member countries was under heavy speculative attacks, and in august 1993 the fluctuating bands was widened to ±15%. In practice, the new band meant giving up their fixed exchange rate system, see Sørensen and Whitta-Jacobsen (2005).

3.5 Floating exchange rate

The connection between home and foreign interest rates during fixed exchange rates can been seen in the light of what economists call the “Impossible Trinity”. A macroeconomic policy regime can only achieve two out of the following three policy goals: A fixed exchange rate regime, free cross-border capital flows and an independent monetary policy. When there is perfect capital mobility and fixed exchange rate, the interest rate has to be equal to the foreign interest rate to keep the expected depreciation rate equal to zero, in accordance with the UIP condition. If a country wants to set its own interest rate independent of the foreign interest rate, it has to let its exchange rate vary given free capital mobility. Alternatively, a fixed exchange rate and free interest rates require strict capital controls. Thus, to achieve all three policy goals is in fact unfeasible.

Usually, most countries choose to have free cross-border capital controls, to encourage economic growth and trade through easy access to capital. As a result, each country has to decide between two options: Dependent or independent monetary policy. When choosing independent monetary policy, it must also adopt floating exchange rates. The advantage with independent monetary policy is that the country can set interest rates according to need in the economy, which may give a stable economic environment. The benefit of fixed exchange rates and a dependent monetary policy regime is that it gives predictability for trade and stable prices. Which regime to choose depends on the valuation of the different pros and cons in question.

There are two main types of floating exchange rate regimes: clean float and dirty float. In a clean float regime, the exchange rate is not in any way influenced by the government or central bank. In a dirty float the central bank can buy foreign currency or sell domestic currency in an attempt to keep the exchange rate more stable.

The most usual type of target in a floating exchange rate regime is some kind of inflation target. They can either have a strict inflation target, where low and stable inflation is the only goal, or a more flexible inflation target, where the central bank can pursue other targets as long as the inflation is stable and close to the target. When a country has exchange rate targeting or money supply targeting, the central bank can react with its instruments immediately and see the reactions instantaneously. Hence, the central bank can keep the exchange rate or money supply within a band. By contrast, when the central bank has an inflation target, it can only influence the inflation rate in the periods ahead and only observe the inflation in previous periods. Thus, the central bank has to respond to the past to get the inflation back on target in the future. To keep the inflation at target at any time is impossible.

The way the central bank reacts on changes in the inflation is by adjusting the interest rate. We see that an increase in the interest rate will appreciate the exchange rate (decrease E). How much a change in the interest rate affects the exchange rate depends on the capital mobility (μ), the expectations ($e_e^{'}$) and the portfolio composition effect (γ)[12].

$$\frac{dE}{di} = -\frac{1}{\frac{\gamma}{\mu E} - e_e^{'}} < 0$$

We know that the supply of foreign currency increases when the domestic interest rate rise (see equation 11). Thus, the effect on the exchange rate of an increase in the interest rate is stronger if the capital mobility (μ) is high, see Figure 3. The higher the level of $|e_e^{'}|$the smaller the effect of the interest rate will be.

We can summarize the exchange rate as a function of supply of foreign currency, where supply is determined by the interest rate differential and the expected depreciation rate.

$$E = E(i, i^{*}, e_e)$$

[12] For more details about the calculations, see Rødseth (2000) p.26.

3.6 The Medium and Long Run.

The portfolio model is a stock model which is first and foremost relevant in the short run analysis. It has emphasis on changes that happens when investors reallocate their portfolios from day to day to achieve highest expected return. From day to day and in the short run factors like the interest rate deviation, devaluation- and depreciation expectations explain most of the change in the exchange rate (in a float regime).

However, since I look at quarterly data in the empirical part of the thesis, it is relevant to open up for other (”flow model”) variables as well.

3.6.1 The Current Account in the Medium Run − the Flow Approach.

The current account is the sum of balance of trade, net factor income and net transfer payments. Balance of trade is exports minus imports of goods and services. Factor income is interest rates and dividends, and transfer payments are foreign aid or other transfers to and from abroad.

When a country has a surplus in the current account, it acquires foreign assets. As a result, domestic investors might rebalance their portfolios, such that both the supply of foreign assets and demand for NOK assets increase. Over time this will lead to an appreciation of the domestic currency under floating exchange regime, or to an increase in the foreign exchange reserves under a fixed exchange rate regime (see Figure 4).

Norway is the fifth largest oil exporter in the world[13], and in 2007 the oil producing sector stood for 24% of GDP. The export of oil and gas made up 43% of the total export in 2009 and are one of the main reasons why Norway has a huge trade surplus. This implies that the petroleum producing sector has a huge impact on the Norwegian economy. The oil producing companies has usually all their income in dollars or pound, but have to pay taxes in NOK. The petroleum tax consists of the ordinary corporation tax corresponding to 28 per cent of their profit and an additional tax, due to exceptional opportunities of making profit, on 50 per

[13] In 2008, http://www.regjeringen.no/nb/dep/oed/tema/olje_og_gass.html?id=1003

cent. This tax has to be paid every second month and consists of huge amounts. As a result, the oil producing companies will have to supply foreign currency to get NOK to pay for their taxes, see Romstad (2008). Both the current account surplus and the petroleum companies' currency supply can give an upward pressure on the NOK.

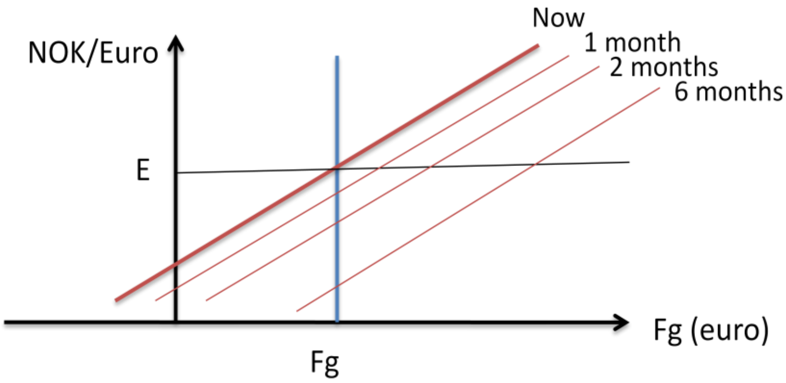

Figure 4 the effect over time of a current account surplus[14].

Norway's revenue from the petroleum sector is invested abroad through the Government pension fund. This is done in order to have sustainable economic revenues from a temporary source of income and to avoid Dutch disease. If the domestic activity is largely dependent on petroleum revenues, there would be a tight connection between the oil price and the NOK exchange rate. The Government Petroleum Fund is there to make the domestic activity less contingent on the petroleum revenues. Thus, it is contributing to make the NOK exchange rate less dependent on oil price (Bernhardsen and Røisland (2000)). Such a conclusion is also supported by the findings in Bjørnstad and Jansen (2007).

3.6.2 Expectations

Equation 4 in the model defines the expected depreciation and how it only depends on today's exchange rate. This is a major simplification. In practice, expectations are based not solely on the level of the exchange rate today, but also on many other factors which can affect the exchange rate, like real exchange rate, development in the world financial markets and prices of dominating goods. If we collect all the factors in Z, we have a new model of expectations:

[14] Figure 1.7 in Rødseth 2000.

$$e_e = e_e(E, Z)$$

Where $Z = h(\varepsilon, P^{oil}, world\ market, speculations, \ldots)$

- *The real exchange rate* ε.The real exchange rate is the relative price level between countries expressed in a common currency.

$$\varepsilon = \frac{EP^*}{P}$$

  This converges towards a stable level in the long run, called steady state. If investors believe that the real exchange rate is higher now than its steady state level, they will expect the exchange rate to depreciate over time, such that the real exchange rate converges towards its steady state. Similarly, if there is a jump in foreign- or domestic price level, the exchange rate will correct the relationship so that the ε tends to its long run level. A high/low real exchange rate will then create expectations about a nominal change in the exchange rate.

- *World market.* In the short run, happenings in the world and world financial markets can have huge impacts on the exchange rate. When the investment bank Lehman Brothers collapsed on September 15th 2008, the reaction in the world financial markets was an increased risk premium in the entire world (Gjedrem (2009)). This decreased the supply of foreign currency and the NOK depreciated.

  Upheavals in the world markets are often followed by great uncertainty in the foreign exchange markets and investors escape to big and safe currencies which are labeled as "safe havens". Under the financial crisis, investors fled from small currencies, like the NOK, to big currencies like the dollar and euro. The "safe haven" currencies are often big and can withstand huge unrest in the capital markets without big fluctuations, compared to smaller currencies. This explains why smaller currencies usually are more volatile than the bigger "safe havens". Furthermore, "safe haven" currencies can experience a negative risk premium, because investors are willing to "pay" (in the form of lost expected return) to hold the currency to avoid risk. Such insurance properties might be one of the reasons behind the great depreciation of the NOK/euro exchange rate in 2008.

In 2002 there was unrest in the Middle East. Investors wanted to secure themselves against the risk of a sharp increase in the oil price. Since the NOK was expected to be connected to the oil price and expected to appreciate when the oil price increased, the NOK was seen as a safe haven. The risk premium fell and the demand for NOK increased (Naug (2003)).

- *Dominating goods.* If a country is a major exporter or importer of certain goods or raw materials, the price of these commodities may also affect the expectations about the exchange rate. A price change in these commodities may have an effect on the whole economy in the medium and long run (see discussion about current account surplus in previous subchapter).

- *Speculations* see chapter 3.4.1.

As a result, in practice, the nominal exchange rate is a function of interest rates and variables that affect the expectations:

$$E = E(i, i^*, e_e, Z, \dots)$$

4 Empirical Results.

4.1 Where do we stand?

Even today in 2010, very few of the theoretical assertions made in theories of exchange rate determination have been proven to have an effect empirically. Some studies have found some evidence for the theoretical hypothesis about long-run relationships, but the empirical results on daily and monthly basis are very poor. For a more thorough discussion about this puzzle, see Sarno (2005) or Frankel and Rose (1995)

> ”The international finance profession has not yet been able to produce theories and, as a consequence, empirical models which allow us to explain the behavior of exchange rates with a reasonable degree of accuracy.” (Sarno 2005)

The legendary paper ”Empirical exchange rate models of the seventies: Do they fit out of sample” by Meese and Rogoff in 1983 compared models of exchange rate determination based on their out-of-sample forecasting and explanatory power. Their finding was that a simple Random Walk model outperformed all the other models as a predictor of exchange rates. Moreover, the models have not improved much since the seventies according to recent literature (Naug (2003), Sarno (2005), Frankel and Rose (1995)).

4.1.1 Order flows

In recent decades a new model based on microstructure theory has found place in the exchange rate theory. The new model is based on order flows, which are net currency transactions. If one participant buys 20 units of Norwegian Kroner, while another sells 15 units, then the order flow volume equals 5 units. A positive amount leads to positive pressure in the market and the NOK may appreciate. A negative amount may lead to depreciation.

The price of currency is determined through multiple steps. First the market participants observe and interpret information about macroeconomic fundamentals and set an order to the market makers. Next, the market makers in the exchange rate market can get access to the participants’ beliefs and information through the order flows. Thereafter, each of them set their price in the light of this information. In such a way, information has a major role in order flow theory. The role of information determines the price through two channels: One direct, where news have a direct effect on the exchange rates, and one indirect, where the participants' heterogeneous beliefs are included by the order flows. The order flow works as a mechanism, which gathers price relevant information like changes in expectations, the participants' opinion about macroeconomic news and shocks that affect the demand in the market. In this way, order flows work as a proxy for the fundamentals and can be used to predict the exchange rate.

The main findings are that there exists a strong connection between order flows and the daily exchange rate. It is also found that different customer segments have different impact on the exchange rate, because of different use of currency and beliefs about exchange rates. For more on order flows, see Romstad (2009) and Rime and Sojli (2006).

4.2 Norwegian Macro Econometric Results

My plan for the rest of this thesis is to explore NOK/Euro exchange rate determination in the medium to long run in this millennium. I will use the article by Bjørnstad and Jansen (2007) as a reference point for my analysis of an inflation targeting regime. Bjørnstad and Jansen tested how a transition from a regime with exchange rate targeting to a regime with inflation targeting affects the exchange rate determination in a small open economy. In the end of the chapter I will investigate how their model fit out of sample, compared to a Random Walk model.

4.2.1 The Model in the Bjørnstad and Jansen Study

The studies of Bjørnstad and Jansen (2007) follow an empirical investigation by Bjørnland and Hungnes (2006), who tested whether two long run parity conditions hold empirically using data on Norway and Europe. In addition to testing the UIP condition ($i - i^* = e_e$) from the capital market, they tested the Purchasing Parity Condition (PPP). The PPP condition comes from the goods market and states that the national price levels should be equal when expressed in a common currency, see Sarno (2005). Hence, the real exchange rate ε (see chapter 3.6.2) should be equal to one in the long run. The real exchange rate ε is:

$$\varepsilon = \frac{EP_*}{P} = 1 \,, \quad \text{and in logs:} \quad ln\varepsilon = lnE - lnP + lnP^* = v - p + p^* = 0$$

PPP is a parity condition that assumes no trade costs. Since trade is costly, the PPP condition does usually not hold at each point in time. In any case, the real exchange level can still bring information about the price level differences between countries over time. Thus, ε may be interpreted as a measure of the deviation from PPP, and it must be stationary for the long-run PPP to hold (Sarno 2005).

The PPP condition and UIP condition are strongly related. Shocks can force the real exchange rate away from PPP, either by increased domestic- or foreign price levels or by the exchange rate. This shock may force the central bank to respond by a change in the interest rate, to keep the exchange rate fixed or inflation stable. The change in the interest rate differential may encourage massive movements in the capital flow, since the risk premium change. This can keep the exchange rate away from purchasing parity for long periods according to Bjørnland and Hungnes (2006).

Bjørnland and Hungnes use data on the NOK/euro exchange rate from first quarter in 1983 to the second quarter in 2002. After testing they came up with a combined PPP and UIP equilibrium correction (ECM) model for the change in the NOK/euro exchange rate.

Below I reproduce equation (9) in Bjørnstad and Jansen (2007):

$$\begin{aligned}\Delta v_t = const &+ \underset{(0.26)}{1.25}\Delta p_t + \underset{(0.25)}{0.65}\Delta p_{t-2} - \underset{(0.41)}{1.56}\Delta p^*_t - \underset{(0.41)}{1.31}\Delta p^*_{t-3} \\ &+ \underset{(0.73)}{2.72}\Delta i_t - \underset{(1.09)}{2.47}\Delta i^*_{t-2} - \underset{(0.05)}{0.27}(v - p + p^*)_{t-1} - \underset{(0.35)}{1.86}(i - i^*)_{t-1} \\ &+ dummies + \hat{\varepsilon}_t, \ \text{ where } dummies = D93q1, D97q1, D02q2\end{aligned}$$

$$\hat{\sigma} = 1.05\% \qquad\qquad T = 1983q1 - 2002q2 = 78$$

The variables are: The log of nominal NOK/euro exchange rate ($v = lnE$), Norwegian and euro zone (trade weighted) consumer prices (p and p^*) and Norwegian and euro zone (trade weighted) 3-months money market interest rates (i and i^*). All variables are in log and are lagged in different ways. Insignificant variables have been omitted from the equation. We see that domestic inflation has a positive effect and foreign inflation has a negative effect on the exchange rate determination. The effect of domestic and euro zone interest rate changes have strong effects on the exchange rates.

In the long run both the PPP and the UIP conditions converge towards a stationary level. We see that when the PPP condition does not hold, there is a correcting mechanism in the next period in an effort to keep the PPP at its steady state in the long run. The interest rate differential in the UIP condition has a similar impact on the next period exchange rate. When the interest rate differential increases, it will result in an increased rate of depreciation, which will result in lower exchange rate in the next periods. This is exactly what the UIP condition states. Similarly in the portfolio model, a higher domestic interest rate will increase the risk premium on the domestic currency. As a result, more investors will shift the portfolio from foreign to domestic currency. Thus a higher risk premium gives a lower exchange rate.

All the short run price coefficients are larger than one, which may be consistent with overshooting. In the long run they will be one in absolute value, in accordance with long run PPP. A conspicuous and somewhat strange result is represented by the signs of the short run interest rate variables Δi_t and Δi^*_{t-2}. Notice that when the domestic interest rate increases, it will lead to higher exchange rate and a depreciation of NOK. This is in conflict with what the portfolio model states. Bjørnland and Hungnes explain the apparent contradiction in the following paragraph:

> "Historically, Norges Bank has increased the interest rate when there have been a depreciating pressure, and reduced the interest rate when there was an appreciation pressure. An increase in the interest rate differential has therefore often coincided with a weaker exchange rate, while an interest rate increase may have prevented the exchange rate from falling even further" (Bjørnland and Hungnes (2003)).
>
> "In the long run, however, the exchange rate will eventually move towards equilibrium. The equilibrium correction terms have the expected sign, so that the exchange rate adjusts in the right direction" (Bjørnland and Hungnes (2006)).

A critique against the study is that Bjørnland and Hungnes have not put much focus on the qualitative difference between the different monetary regimes that were operating during the sample period. Norway had fixed exchange rate regime until 1992, first against a trade weighted currency basket, and from 1990 against the ECU. From 1992, Norway then changed to a floating exchange regime, first with an exchange rate target and from March 2001 inflation target.

> "Switching from a fixed exchange rate to a floating rate - which changes the way expectations are formed - changes the behavior of nominal and real exchange rates and the ability of the UIP to explain exchange rate changes." (Quote by C. Neely and L. Sarno (2002) in Sarno (2005)

Different monetary regimes may lead to different values of the variables in different points in time in the econometric analysis. Bjørnland and Hungnes have reported Chow statistics and constancy graphs, and concluded that there exist no such effects of the regime shifts. The reason may be that only the four last data points includes the new regime, giving it little effect on the rest of the data. Nevertheless, a central question remains: Would including the regime shifts give a better fit and short run interest rate effects with the expected sign?

4.2.2 What Happened after the Monetary Policy Regime Change?

As mentioned, the starting point of Bjørnstad and Jansen's study is the model of Bjørnland and Hungnes (2006). The authors aimed to closer examine how the exchange rate equation responds to the regime shift in March 2001. They reasoned that in an exchange rate targeting regime interest rates are only used to stabilize large movements in the exchange rate, after the use of interventions have failed. When shifting to an inflation targeting regime the use of interest rates will change. Interest rates will now be used to regulate domestic demand to stabilize the inflation (Bjørnstad and Jansen (2007)).

Bjørnstad and Jansen extend the dataset to include third quarter of 2006, and re-estimate the model. The original specification of the equation gets rejected, because the relationship between the variables breaks down after the regime shift. They also experienced significant forecast failure.

As a result of this, Bjørnstad and Jansen came up with a new ECM model, including a set of new variables which could detect possible effects of the monetary policy regime shift.

This is the resulting regression equation from Bjørnstad and Jansen (2007, eq.10):

$$\begin{aligned}
\Delta v_t &= const + \underset{(0.16)}{0.89}(\Delta p_t - \Delta p_t^*) - \underset{(0.16)}{0.47}(\Delta p_{t-1} - \Delta p_{t-2}^*) \\
&- \underset{(0.05)}{0.24}\Delta_2 v_{t-1} - \underset{(0.004)}{0.024}\Delta_4 p_t^{oil} - \underset{(0.28)}{1.70}\Delta\Delta p_t^{jae} STEP_{2001q2} \\
&- \underset{(0.99)}{9.68}\Delta_3 i_t STEP_{2001q2} + \underset{(1.93)}{16.33}\Delta_3 i_{t-1}^* STEP_{2001q2} \\
&- \underset{(0.03)}{0.10}(v - p + p^*)_{t-1} - \underset{(0.22)}{0.79}[(i - \Delta p) - (i^* - \Delta p^*)]_{t-1} - \underset{(0.0026)}{0.006} p_{t-1}^{oil} \\
&+ dummies + \widehat{\varepsilon}_t
\end{aligned}$$

$$\text{where } dummies = D93Q1, D97Q1, DUM98, D01Q2, D03Q2,$$
$$\text{and} \quad DUM98 = D98Q3 + D98Q4 - D99Q1 - D98Q2$$

After the introduction of the inflation targeting regime, new variables are included to detect changes in the new monetary policy. The new variables are the growth in core inflation ($\Delta\Delta p_t^{jae}$), which is seen as an expectation variable. Since the central bank targets the core inflation, a change in this variable may signal a future interest rate change. To ensure that this effect only comes into the regression after the regime shift, a step dummy has been included to interact with the core inflation. The step dummy: $STEP_{2001q2} = 1$ after the inflation target in first quarter of 2001. The step dummy also interacts with changes in the national or euro zone interest rate, which captures the short run dynamics. They also included the oil price as a new explanatory variable. Insignificant variables are left out. Notice that including a short run interest rate dynamic under inflation targeting, renders the change in interest rates insignificant on its own, and are thus left out.

There is a minor recording error in equation 10[15]. The dummy DUM98 should be symmetric:

DUM98= D98Q3 + D98Q4 - D99Q1 - D99Q2.

Their most relevant result is that the short term effects of the interest rates after the monetary policy regime changed sign from the results in Bjørnland and Hungnes (2006), in such a way that it better fits the theory. The reason is that a regime shift reverses the direction of the causal effect between changes in the nominal exchange rate and interest rates changes.

[15] According to E. Jansen by mail on March 18th 2010.

> “When the central bank targets the exchange rate, interest rates are rarely used and only to counteract large movements in the exchange rate when interventions have failed. With inflation targeting the interest rate is used to stabilize the domestic economy and the exchange rate responds strongly to interest rate changes with the expected sign” (Bjørnstad and Jansen (2007,p14)).

In the long run both Bjørnstad and Jansen (2007) and Bjørnland and Hungnes (2006) gets the same result, that is, a change of monetary policy regime does not change the long run relationship.

4.3 Replication on an Extended Data Set.

In this section I first replicate the findings of Bjørnstad and Jansen (2007), with the dataset I was given by the authors upon request. Although the results are not exactly identical (see Table 2), for practical purposes the results are close enough. These minor deviations from the original results and test statistics may be due to small data revisions that might have taken place after the publication but prior to the construction of the dataset that was available for me. A somewhat less likely cause may be differences between the econometric software used: I use OxMetrics 6 /PC Give 13, while Bjørnstad and Jansen have been using OxMetrics 4/PC Give 11.

Next, I report how the regression responds to an extended dataset which include first quarter of 2008. I will use the beginning of 2008 as the start of the financial crisis, even though the most used starting point of the financial crisis was with the official bankruptcy of the Lehman Brothers on the 15th September 2008. I do so since investors and governments all around the world started anticipating trouble prior to the collapse of Lehman Brothers, which affected the expectations and actions to the participants in the foreign exchange market.

We see that by extending the dataset to include the quarter before the financial crisis the equation still works. Also notice that when we include more data from the inflation targeting regime, the interest rates dominates the equation even more.

When we extend the data to include the second quarter of 2009 and the financial crisis, and the re-estimate the model, a massive rejection of the specifications occurs, see Table 3.

The misspecification tests show that the model no longer fits the data. In addition, there is a pronounced drop in the $adjusted\ R^2$. Thus, the events happening during the financial crisis changes the relationship between the variables.

The last column is the results from the regression using the equation by Bjørnstad and Jansen on data after the inflation targeting regime in 2001. Although the misspecification tests are mostly insignificant, we observe that almost none of the variables are significant. Thus, the equation is no longer a good representation of the data. Such conclusions could also be drawn from Figure 6 1-step forecasts, which is an in-sample one-step-ahead forecast for the relative change in the NOK/Euro exchange rate, from the fourth quarter in 2006 until second quarter 2009. The forecast fails already in its first forecast in the fourth quarter in 2006. The major flaws in late 2008 and 2009 are no surprise, as this was the start of the financial crisis.

The significance of the heteroscedasticity test may be a cause of the increased volatility in the exchange rate after the inflation targeting regime and especially during the financial crisis seen in Figure 5. It may also be due to an omitted variable that may be significant during the financial crisis, since the heteroscedasticity tests also are general misspecification tests.

Table 2 OLS regression results[16] of the Bjørnstad and Jansen model on different sub samples.

Δv_t	Bjørnstad and Jansen	replication	1983(1) - 2008(1)	1983(1) - 2009(2)	2001(2) - 2009(2)
$\Delta p_t - \Delta p_t^*$	0.89**	0.89**	0.92**	1.00**	-0.36
	(0.16)	(0.16)	(0.16)	(0.23)	(0.71)
$\Delta p_{t-1} - \Delta p_{t-2}^*$	-0.47**	-0.47**	-0.50**	-0.58*	-0.66
	(0.16)	(0.17)	(0.17)	(0.25)	(0.66)
$\Delta_2 v_{t-1}$	-0.24**	-0.24**	-0.25**	-0.18*	-0.39
	(0.05)	(0.05)	(0.05)	(0.07)	(0.22)
$\Delta_4 P_t^{oil}$	-0.024**	-0.024**	-0.025**	-0.023**	-0.034*
	(0.004)	(0.004)	(0.004)	(0.005)	(0.014)
$\Delta\Delta p_t^{jae}\ STEP_{2001g2}$	-1.70**	-1.70**	-1.19**	-0.95*	-0.74
	(0.28)	(0.28)	(0.27)	(0.36)	(0.72)
$\Delta_3 i_t STEP_{2001q2}$	-9.68**	-9.69**	-10.07**	-6.48**	-12.02**
	(0.99)	(1.00)	(1.05)	(1.35)	(3.33)
$\Delta_3 i_{t-1}^* STEP_{2001q2}$	16.33**	16.33**	17.74**	10.66**	10.63*
	(1.93)	(1.93)	(2.00)	(2.32)	(4.14)
$(v - p + p^*)_{t-1}$	-0.10**	-0.11**	-0.12**	-0.12**	-0.44**
	(0.03)	(0.03)	(0.03)	(0.05)	(0.13)
$[(i - \Delta p) - (i^* - \Delta p^*)]_{t-1}$	-0.79**	-0.79**	-0.78**	-0.85**	-0.73
	(0.22)	(0.22)	(0.22)	(0.31)	(0.82)
p_{t-1}^{oil}	-0.006*	-0.006*	-0.005	0.004	0.055**
	(0.0026)	(0.0027)	(0.0026)	(0.0028)	(0.0136)
$Adj. R^2$		**0.79**	**0.75**	**0.55**	**0.57**

[16] * significant at 5% level, ** significant at 1% level.

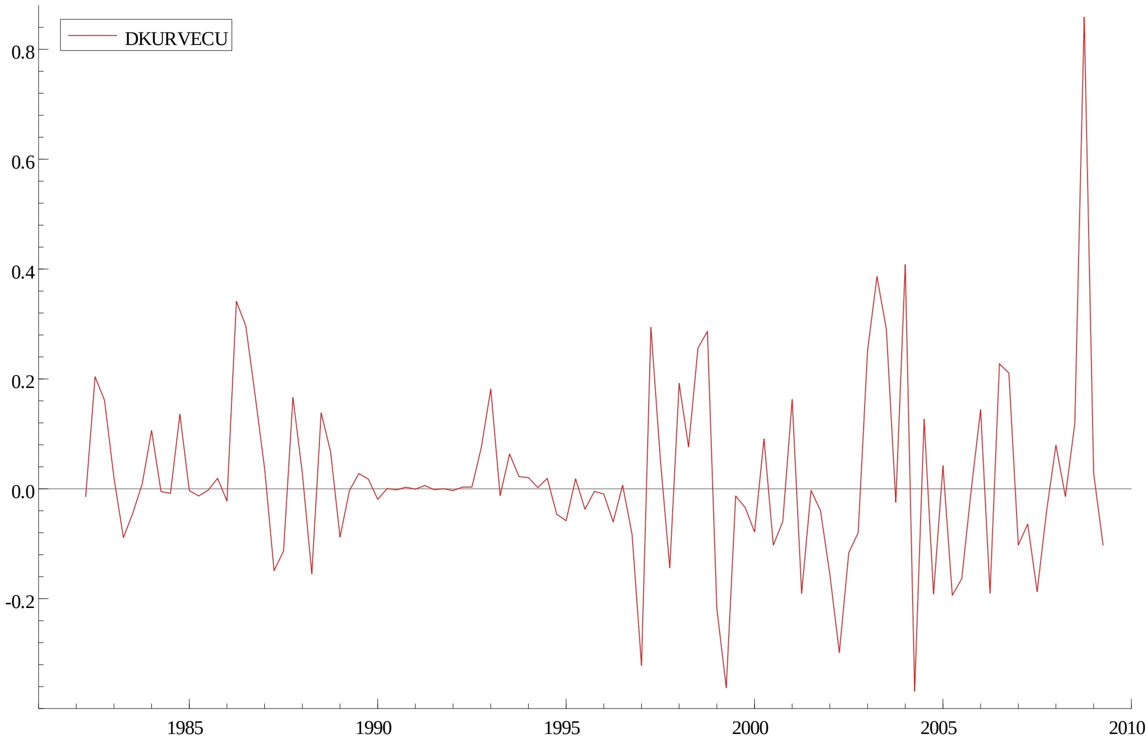

Figure 5 Volatility in the NOK/Euro exchange rate

Figure 6 1-step forecasts (dashed line) with ±2 standard errors bars from 2006(3) to 2009(2) of the Bjørnstad and Jansen model, 95% prediction intervals and outcomes.

Table 3 Misspecification tests

Test statistics:	Bjørnstad and Jansen (1983(1)-2006(3))	Replication 1983(1)- 2006(3)	1983(1) - 2008(1)	1983(1)- 2009(2)	2001(2)-2009(2) [17]
AR 1-5:	F(5,74) = 1.02 [0.41]	F(5,74) = 1.0153 [0.4149]	F(5,80) = 0.8765 [0.5008]	F(5,85) = 2.7845 [0.0223]*	F(3,14) = 0.42463 [0.7384]
ARCH 1-4:	F(4,71) = 0.33 [0.85]	F(4,87) = 0.4102 [0.8009]	F(4,93) = 0.2557 [0.9055]	F(4,98) = 6.2003 [0.0002]**	F(3,27) = 1.8892 [0.1552]
Normality :	Chi^2(2)= 4.33 [0.11]	Chi^2(2) = 4.3282 [0.1149]	Chi^2(2) = 2.6186 [0.2700]	Chi^2(2) = 59.028 [0.0000]**	Chi^2(2) = 5.3507 [0.0689]
Hetero:	F(26,52)= 0.71 [0.83]	F(22,68) = 1.0237 [0.4496]	F(22,74) = 1.0591 [0.4093]	F(22,79) = 6.2865 [0.0000]**	F(20,10) = 3.1914 [0.0316]*
Hetero-X:		F(59,31) = 1.1595 [0.3326]	F(65,31) = 1.5133 [0.1034]	F(68,33) = 31.573 [0.0000]**	not enough observations
RESET23:		F(2,77) = 1.0505 [0.3547]	F(2,83) = 1.1277 [0.3287]	F(2,88) = 3.4976 [0.0345]*	F(2,15) = 2.8590 [0.0887]

Notes: the *AR1–5* is a test for autocorrelated errors from *lag1* to *lag5*; *ARCH 1–4* is a test for 1- 4th-order autoregressive conditional heteroscedasticity in the residuals; the *normality test* checks whether the residuals are normally distributed; *Hetero test* is a test for residual heteroscedasticity using squares (Hetero) and squares and cross products (Hetero-X (only calculated if there is a large number of observations relative to number of variables in the regression)); and *Reset23* test is a regression specification test .(Doornik and Hendry (2009))[18]

[17] OxMetrics used AR 1-3 test and ARCH 1-3 test because of fewer degrees of freedom,

[18] And web page: http://www.pcgive.com/pcgive/batch.html

4.4 Forecasting Properties: Bjørnstad and Jansen versus Random Walk.

In the spirit of Meese and Rogoff I set an objective to test how well the model by Bjørnstad and Jansen performed on out of sample forecasts compared to a simple Random Walk model.

A simple Random Walk model of the exchange rate is a model, where the level of today's exchange rate is solely determined by yesterday's exchange rate and an error term, which indicates shocks.

$$v_t = \alpha + v_{t-1} + u_t$$

The α is a constant which makes it possible to start somewhere else than at the origin. Thus, the accurate name of this model is a Random Walk model with drift. Notice that the lag of the exchange rate has a coefficient which is restricted to one.

Since the Random Walk model estimates the value of the exchange rate and Bjørnstad and Jansen's model explains the rate of change of the exchange rate, the forecasts of the two models cannot be compared directly. However, in principle, it is easy to get around this problem by re-writing the Bjørnstad and Jansen model with the level of the exchange rate on the left hand side of the equation. In practice I make use of an equivalent solution, which involves the use of an identity for the level variable v_t, meaning that the analysis of the forecast performance is done in a multi-equation setting. Of course, including the identity for v_t will not change the performance of the model.

Thereafter, I estimate the system with the First Step Least Square (1SLS) method. The result is that the output can be made in the form of levels, like the Random Walk, instead of differences. When both equations produce estimates of the levels we can compare them. I estimate both models up to the third quarter of 2006, applying the dataset from Bjørnstad and Jansen. Subsequently, I forecast both models with 11 periods, which is up to second quarter of 2009, using 1-Step Ahead forecast method. 1-Step Ahead forecasts project one period ahead and then use the results from the forecast for the next period forecast and forward. In 1- Step Ahead forecast all other present variables are assumed known. Since Bjørnstad and Jansen's model is the only structural model with other variables, their model benefits from such an assumption. The assumption that all the other variables are known in the beginning of each period, lets the Bjørnstad and Jansen model move in the correct direction even though the exchange rate forecast may be wrong. The results from the forecasts are represented in Figure 7, where the bars represent the forecast standard errors.

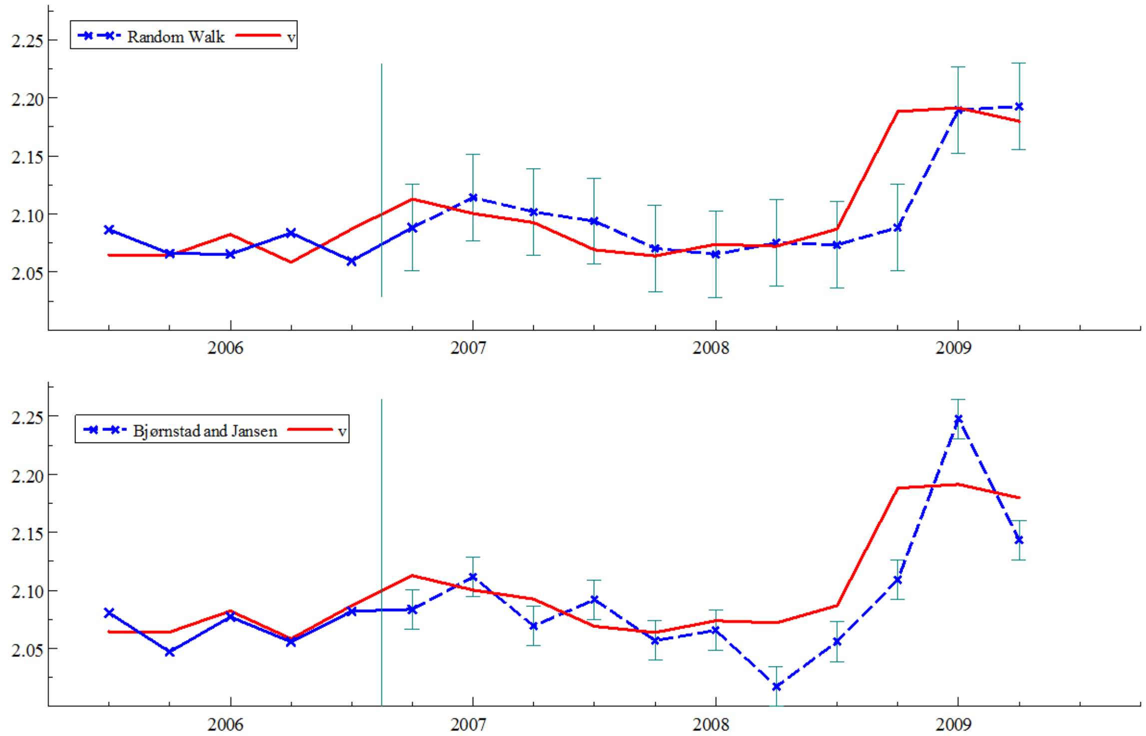

Figure 7 1-Step Ahead forecasts comparison with ±2 standard errors bars, Random Walk and Bjørnstad and Jansen model. The solid line is the actual value of the exchange rate and estimation, while the dashed line is the forecast.

From Figure 7 we see that Bjørnstad and Jansen fail to forecast correctly already in the fourth quarter of 2006. Their model also have great forecast failure from second quarter of 2008 and onwards. The Random Walk model only fails to forecast the fourth quarter of 2008. This is somewhat special, because the Bjørnstad and Jansen model base their forecasts on actual realized values of future explanatory variables.

Instead of representing the forecasts in figures, it is possible to instead calculate the accuracy of the forecast. The most popular way to calculate the accuracy, and the way done by Meese and Rogoff is with the root Mean Square error (RMSE) method. The RMSE squares the values of the forecast errors, next makes an average of the squared forecast errors and then takes the square root of this[19]. In this way it weights the large forecast errors more heavily than the smaller ones and over- and underpredictions of the same magnitude has the same cost. The method is appropriate when the cost of the error increases as the size of the error increases. It is thus sensitive to huge outliers. The RMSE results from the forecasts can be found in Table 4. We see that the 1-step-ahead forecast error is smaller in the Random Walk model than the Bjørnstad and Jansen model.

The financial crisis in 2008 and 2009 could be characterized as a shock to the system which could not be foreseen by our variables. In order to examine whether this is the case and to investigate whether the models would perform differently without the financial crisis I create two forecasts, one up to the financial crisis and one including the financial crisis, see Table 4. We can see that the Random Walk still will do better than the Bjørnstad and Jansen model in 1-Step Ahead forecasting, even though Bjørnstad and Jansen should have a benefit in this type of forecasting.

Table 4 Root Mean Square errors (RMSE), RMSE*100.

Forecast period	**2006(3)-2008(1), 6 quarters**		**2006(3)-2009 (2), 11 quarters.**	
Forecast type	1-Step Ahead	Dynamic	1-Step Ahead	Dynamic
Bjørnstad and Jansen	1.9	**1.9**	3.9	6.1
Random Walk	**1.6**	2.1	**3.3**	**4.9**

Another, and maybe more relevant in practice, way of forecasting is with dynamic forecasts. In 1-Step Ahead forecasts, all other variables than the exchange rate are assumed known. In Bjørnstad and Jansen the lag or difference of the exchange rate is included several places. A 1-step-ahead forecast assumes these values known at actual values, which gives Bjørnstad and Jansen a huge benefit compared to Random Walk. In dynamic forecasting all these values are affected by the forecasts for each period. The forecast for this period will have feedbacks to the lags and differences, which again will affect the next periods forecast, resulting in a dynamic process. The results of dynamic forecast of the Random Walk and Bjørnstad and

[19] RMSE = $[\ 1/H \sum_{t=1}^{H} (y_t-f_t)^2]^{1/2}$,where the forecast horizon is H, y_t the actual values, and f_t the forecasts

Jansen model are illustrated graphically in Figure 8. The difference in the forecast standard error bars is due to the setup of the models. While the Bjørnstad and Jansen forecast errors will converge towards a constant, the Random Walk forecast errors will increase as the number of forecasts increase, see appendix D.

We see that the Random Walk model forecasts including third quarter of 2008 are close to actual values, while the Bjørnstad and Jansen forecasts only performs well up to first quarter of 2008. The model by Bjørnstad and Jansen has a small advantage in dynamic forecasting in periods without huge fluctuations in the exchange rate. Neither of the models did foresee the impact from the financial crisis in 2008 and 2009. Random Walk outperforms the model by Bjørnstad and Jansen both with 1-Step Ahead forecasting and with dynamic forecasting when forecasting up and through second quarter of 2009. This is most likely a consequence of the way the models are constructed (see chapter 5.4).

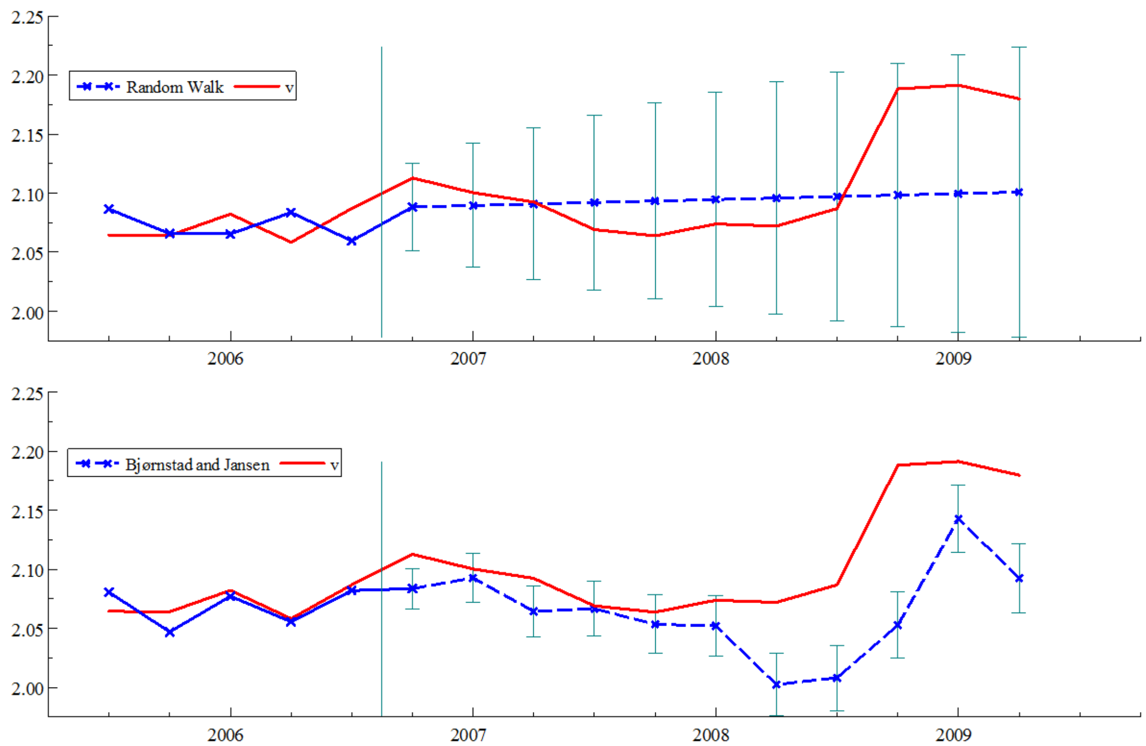

Figure 8 Dynamic forecasts comparison with ±2 standard errors bars, Random Walk and Bjørnstad and Jansen model. The solid line is the actual value of the exchange rate and estimation, while the dashed line is the forecast.

It might be interesting to check whether the difference in 1-step-ahead forecast performance is statistical significant. In order to investigate this matter, I employ the Morgan-Granger-Newbold (MGN) test (see Clements (2005)). When the forecasts are unbiased the model with the best forecasts is the one with the smallest expected squared error. The model with the smallest expected forecast errors is the one with the minimum forecast error. It follows that the MGN-test tests if the variances of the different forecasts are equal. In accordance to the null-hypothesis the two forecasts are equally accurate on average. The assumptions made are that the loss of forecasts is squared (like the RMSE) and that the forecast errors have zero mean, are normally distributed and serially uncorrelated.
The test statistics is:

$$\frac{r}{\sqrt{(T-1)^{-1}(1-r^2)}} \sim t_{T-1}$$

where

$$r = \frac{\boldsymbol{u}_1'\boldsymbol{u}_2}{\sqrt{\boldsymbol{u}_1'\boldsymbol{u}_1\boldsymbol{u}_2'\boldsymbol{u}_2}}$$

The forecast errors are collected in two column vectors ê and ẽ, where $\hat{e} = \left(\hat{e}_{1+h|1}, \dots, \hat{e}_{T+h|T}\right)'$, $\tilde{e} = \left(\tilde{e}_{1+h|1}, \dots, \tilde{e}_{T+h|T}\right)'$, $u_{1,t+1|t} = \hat{e}_{t+1|t} - \tilde{e}_{t+1|t}$ and $u_{2,t+1|t} = \hat{e}_{t+1|t} + \tilde{e}_{t+1|t}$ and T is number of forecasts, (see Clements (2005, p.12)).

I obtain the value of the test-statistics to be 0.697, which is insignificant under the null hypothesis (at both 1% and 5% significance level with the student-t distribution with 10 degrees of freedom). In other words the forecast difference between Random Walk and Bjørnstad and Jansen is not statistical significant, and we cannot differentiate between them in forecast performance.

5 Exchange Rate Modeling in the Period of Inflation Targeting Regime

Since some of the features and properties of the models made by Bjørnland and Hungnes, and Bjørnstad and Jansen may reflect that they use a sample period that includes the pre-inflation targeting period, I will make an attempt to model the exchange rate only based on data for the period of inflation targeting regime. Among other things, I can then investigate whether a new model can “forecast” the exchange rate during the financial crisis better than the existing models do. I make use of data from second quarter of 2001 to the second quarter of 2008 in the specification of the model.

5.1 From General to Specific

I start with a general model of the change in the exchange rate (Δv_t), with current and lagged exogenous variables and lagged endogenous variables as explanatory variables.

Equation (5.1):

$$\begin{aligned}\Delta v_t = {} & \alpha + \beta_1 \Delta v_{t-1} + \beta_2 \Delta v_{t-2} + \gamma_1 \Delta p_{t-1} + \gamma_2 \Delta p_{t-2} + \gamma_3 \Delta p^*_{t-1} + \gamma_4 \Delta p^*_{t-2} + \gamma_5 v_{t-1} \\ & + \gamma_6 p_{t-1} + \gamma_7 p^*_{t-1} + \gamma_8 i_t + \gamma_9 i_{t-1} + \gamma_{10} i^*_t + \gamma_{11} i^*_{t-1} + \gamma_{12} p^{oil}_t + \gamma_{13} p^{oil}_{t-1} \\ & + \varepsilon_t\end{aligned}$$

The endogenous regressors are the lagged difference of the exchange rate. The exogenous variables are the first and second lag of the growth in foreign and domestic prices ($\Delta p_t, \Delta p^*_t$), the lagged nominal exchange rate (v_{t-1}), lagged nominal price levels ($p_{t-1},\ p^*_{t-1}$), and current and lagged home and foreign interest rates (i_t, i^*_t) and oil price (p^{oil}_t).

5.1.1 Exclusion Restrictions

To see if the relationship could be modeled as a pure autoregressive model, I compare equation (5.1) with a model with only exchange rate dynamics. The model with exchange rate dynamics restricts the coefficients of all the other variables to be equal to zero. In this case this amounts to 12 restrictions. As we can see in Table 5, the null hypothesis is rejected at 1 % significance value for this sub sample, meaning that there might be improvement in the regression by including more variables according to economic theory.

Next, I test if the relationship can be modeled by an autoregressive distributed lag (ADL) model[20] broadly consistent with an UIP relationship with short run dynamics as exogenous variables. I include both contemporary and lagged values of the interest rates. As a proxy for the expected depreciation rate, I also include the oil price since it is an important wealth- and income determinant for the Norwegian economy. An increase in the oil price will give expectations about depreciation in the exchange rate (see chapter 3.6.1 on page 22). Thereafter, I put the restriction that all the remaining coefficients are equal to zero. In total the mentioned conditions sum up to 6 restrictions. As we can see in Table 5, the model cannot be rejected even at 5% significance value, which implies that this relationship can hold according to the sub sample. Nevertheless, some individually significant values can of course "hide" among the joint zero restriction. Such a possibility motivates more modeling.

Table 5 Tests of equation (5.1) for exclusion restrictions

Test for excluding: [0] = Δp_{t-1} [1] = Δp_{t-2} [2] = Δp^*_{t-1} [3] = Δp^*_{t-2} [4] = p_{t-1} [5] = p^*_{t-1} [6] = i_t [7] = i_{t-1} [8] = i^*_t [9] = i^*_{t-1} [10] =p^{oil}_t [11] =p^{oil}_{t-1} Subset F(12,13) = 7.9278 [0.0004]**	Test for excluding: [0] = Δp_{t-1} [1] = Δp_{t-2} [2] = Δp^*_{t-1} [3] = Δp^*_{t-2} [4] = p_{t-1} [5] = p^*_{t-1} Subset F(6,13) = 1.9336 [0.1501]

The same tests were carried out with another equation, where the inflation variable was exchnaged with the variable for core inflation (Δp^{jae}_t). This new test did not, however, give

[20] "autoregressive" because lagged values of the dependent variable are included as regressors, and "distributed lag" because the regression also includes multiple lags of exogenous variables (Stock and Watson (2007, p 543))

any improvement from the previous starting point. The interest rate decision by the central bank is based on the core inflation. Accordingly, the core inflation may be seen as an expectation variable for the interest rate. Since I already have included the interest rate, including the core inflation might not give any more information about the determination of the exchange rate.

5.1.2 Avoiding Multicollinearity

After estimating equation (5.1) and removing all insignificant values, the lagged interest rate does not have the expected sign, see (1) in Table 6. This might be due to high, but not perfect, multicollinearity. With time series data a certain degree of collinearity is common, especially for variables in levels. The correlation between i_t and i_{t-1} is 0.96, see the correlation matrix in Table 8 in appendix C. To avoid this problem with multicollinearity, we re-specify the model with the interest rate in first difference and lagged level. As we see in the correlation matrix the correlation between the change[21] (Δi_t) and the lagged value (i_{t-1}) is reduced to -0.21, and it is no longer seen as a problem. The reparameterization will not have any impact on the accuracy of the model, although it will have small impacts on the coefficients, see (1) and (2) in Table 6. As we observe, the standard error of the equation (σ) keeps the same value after the reparameterization.

5.1.3 Evidence for UIP and PPP Mechanisms.

In order to investigate whether there exists any evidence for the hypothesis of an UIP type mechanism, I include the interest rate differential in the equation. As noted above, portfolio theory says that if the interest rate differential increases, the exchange rate will depreciate. Speculators in the exchange rate market reacts fast to changes in the interest rate in effort to make profits on arbitrage, and the effects from an interest rate change will thus have an immediate effect on the exchange rate. Due to these considerations I choose to include the current period UIP condition. As we can see in (3) in Table 6, the interest rate differential has

[21] I will refer to the difference in the interest rate (Δi) as the change or growth in the interest rate, to avoid confusion with the interest rate differential ($i_t - i_t^*$).

the expected sign and the standard error of the equation (σ) is unaffected by the respecification. Also note that none of the misspecification tests has been significant.

The lagged values of domestic and foreign prices have so far been without a clear economic interpretation, but the statistical tests show that they are relevant explanatory variables. With the purpose of aiding interpretation, I include them as a lagged function of the real exchange rate. To avoid perfect multicollinearity on the other hand, I have to leave out one of the existing explanatory variables. I choose to leave out p_{t-1}. The result is reported in column (4) in Table 6. We see that there exists a real exchange rate relationship. In addition, we can notice that this is still only a mere reparameterization, since the standard error of the equation is the same.

If the coefficients of $v_{t-1}$and p^*_{t-1}in column (4) had been estimated to zero, we would have a perfect real exchange rate relationship. Since this is not the case, the coefficients of $v_{t-1}$and p^*_{t-1}shows how far we are from a perfect real exchange rate relationship. The effect we have in (4) might not show a direct exchange market effect, but might be a result of capturing a "terms of trade" effect or an effect of extrapolative expectations ($e_e^{'} > 0$) in the short run. An increase in the lagged exchange rate will with extrapolative expectations give a higher appreciation this period (since $\beta_{v_{t-1}} > 1$). "Terms of trade" is the relative price of a country's exports to imports. An increase in foreign prices will deteriorate our terms of trade, since imports gets more expensive relative to exports. This may worsen the current account, which may lead to a depreciation of the currency [22](see chapter 3.6.1 on page 22).

[22] http://www.norges-bank.no/templates/article____13711.aspx

Table 6 OLS results for different specifications on equation (5.1), estimated on period 2001(2) - 2008(2)

Δv_t	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δv_{t-1}	-0.49** (0.11)	-0.49** (0.11)	-0.49** (0.11)	-0.49** (0.11)	-0.29* (0.13)	-0.23* (0.11)	
Δp^*_{t-2}	1.02* (0.42)	1.02* (0.42)	1.02* (0.42)	1.02* (0.42)	0.70* (0.55)		
v_{t-1}	-0.42** (0.11)	-0.42** (0.11)	-0.42** (0.11)	1.16** (0.40)	0.19 (0.41)		
p_{t-1}	1.58** (0.35)	1.58** (0.35)	1.58** (0.35)				
p^*_{t-1}	-0.79** (0.28)	-0.79** (0.28)	-0.79** (0.28)	0.79** (0.20)			
$(v - p + p^*)_{t-1}$				-1.58** (0.35)	-0.78* (0.38)	-0.61** (0.12)	-0.38** (0.13)
i_t	-24.44** (2.69)						
i_{t-1}	14.60** (2.18)	-9.82** (1.85)	-7.74** (1.73)	-7.74** (1.73)	9.69** (2.21)	9.56** (2.10)	
Δi_t		-24.44** (2.69)	-6.86** (2.56)	-6.86** (2.56)	-5.20* (3.36)	-4.76 (3.27)	-11.01** (3.44)
i^*_t	17.57** (3.44)	17.57** (3.44)					
$i_t - i^*_t$			-17.57** (3.44)	-17.57** (3.44)	-22.05** (4.33)	-21.60** (4.12)	-3.89* (1.70)
p^{oil}_t	-0.057** (0.0154)	-0.057** (0.0154)	-0.057** (0.0154)	-0.057** (0.0154)	-0.018* (0.016)	-0.021* (0.011)	0.015 (0.0102)
Equation standard error (σ)	**0.0090165**	**0.0090165**	**0.0090165**	**0.0090165**	**0.011973**	**0.0118627**	**0.0160983**

5.1.4 Econometric Decisions

The effects of $v_{t-1}$and p^*_{t-1} might be influenced by multicollinearity, since both home and foreign prices and the exchange rate are mutually correlated. We see in the correlation matrix in appendix C that foreign and home prices are highly correlated. Because of this the coefficient results may be biased. To check for this I tried to put zero restrictions on $v_{t-1}$and p^*_{t-1} and test for exclusions. If the effect is only caused by multicollinearity, this exclusion would not be rejected. Unfortunately, the test gets rejected at 1% significance value, meaning that both variables are significant and that not all the explanatory power of the variables is caused by multicollinearity. This results in an econometric issue: Shall we include the significant values, even though the coefficients cannot be explained by economic theory and thus cause confusion, or shall we leave them out which can cause specification error and a higher standard error of the equation?

Even though both $v_{t-1}$and $p^*_{t-1}$are significant, we might still have an element of multicollinearity bias. In an effort to exclude the multicollinearity effect, we restrict the coefficient of $p^*_{t-1}$to be equal to zero. We see in (5) that removing $p^*_{t-1}$from the regression renders v_{t-1} insignificant and close to zero, giving support to the hypothesis of a multicollinearity bias. A drawback of the restriction is that we get an increase in the standard error of the equation and a lowering of the significance of the other regressors. Still note, that neither of the misspecification tests are significant.

If we in addition restrict the coefficient of $v_{t-1}$to be equal to zero, the standard error of the equation is improved, and some of the other regressors become more significant. Also note that Δp^*_{t-2} becomes insignificant and is left out of the last modeling (see (6) in Table 6).

5.1.5 An Unwanted Effect.

As the observant reader may already have noticed, restricting p^*_{t-1} out of the regression leaves the lagged interest rate (i_{t-1}) very significant with the “wrong” sign. When we in addition also leave v_{t-1} out, the effect of the lagged interest rate renders the change in the interest rate (Δi_t) insignificant. After investigating whether this effect is a result of the specification of the model or a result of the data used, we find no evidence to support that the effect was made by a construction error. Yet, this effect might again be due to correlation between regressors.

The lagged interest rate is highly correlated with the home and foreign interest rate differential $i_t - i_t^*$, with a correlation of 0.94714 (see the correlation matrix in Table 8). Thus, if we leave it out, we might avoid some of the bias. Because of the short sample period, small coincidences may give huge effects and significance, which might be best omitted.

The result after restricting i_{t-1} to be equal to zero is reported in column (7) in Table 6. Further on, note that the lagged change in exchange rate Δv_{t-1} was reported insignificant and is left out.

In order to check whether the restrictions in (7) in Table 6 can be done, I perform an F-test. I employ the model in column (4) as the unrestricted model, which has 10 regressors including the constant. Compared to (4), the model in column (7) has three restrictions. The total number of observations is 29, while the null hypothesis is that all the restrictions are equal to zero ($\beta_{p^*_{t-1}} = \beta_{v_{t-1}} = \beta_{i_{t-1}} = 0$). The model gets rejected at 1% significance level, meaning that the restrictions can not be done on the data at hand. Another implication is that the restricted model is significantly poorer than the unrestricted model in explaining the development in the exchange rate. I assume that these results are due to the collinearity issue discussed above, and I keep the model in column (7) with its restrictions as my final model.

The remaining and very important virtue of this model is that none of the misspecification tests are significant. This means that we still can make inference about the variables based on the t-values and F-statistics.

As we see in the table, omitting i_{t-1} amplifies the standard error of the equation. This exclusion also decreases the level of significance on some of the other variables. The effect of the home and foreign interest rate differential, which is the cornerstone in the UIP condition and important in the portfolio theory, is significantly decreased. The only improved variable is the change in domestic interest rate (Δi_t), which now includes the effect of the lagged interest rate (i_{t-1}). The change in interest rate has now the strongest effect on the development of the exchange rate.

The final model looks like this (same as column (7) in Table 6):

Equation (5.2):

$$\Delta v_t = \alpha - 0.38(v - p + p^*)_{t-1} - 3.89(i_t - i_t^*) - 11.01\Delta i_t + 0.015 p_t^{oil} + \varepsilon_t$$

5.2 Economic Interpretation.

Relative to the Bjørnstad and Jansen model, my model has a simpler structure. It is a small model, but the virtue is that it only contains theoretical and explainable variables. The model has obviously a higher degree of explanation than a Random Walk model, since the restricted model gets rejected at 1% significance value during an F-test.

5.2.1 The Power of Interest Rates.

The home and foreign interest rate differential is a relevant explanatory variable, as the portfolio theory and UIP condition states. If the interest rate differential increases by 1 percentage point $(\Delta(i_t - i_t^*) = 0.01)$, then the change in the exchange rate will be -3.89%. The long run impact of a permanent increase in the interest rate differential with 1 percentage point is a permanent appreciation of the NOK/euro exchange rate of 10.2%. Thus, the result is in line with the portfolio theory: If the interest rate differential increases, then the NOK/euro exchange rate will appreciate.

What may be on the side of the portfolio theory in my model is the effect of the change in the interest rate (Δi_t). The content of this effect says that in the short run, domestic interest rate changes have a huge effect on the determination of the exchange rate. If both the domestic and foreign interest rate increase with one percentage point $(\Delta i_t = \Delta i_t^* = 0.01)$, in such a way that the interest rate differential is unchanged, the exchange rate will appreciate 11.01% in the short run. However, this will have no effect in the long run. This result will come in addition to the more medium run effect of the change in the interest rate differential, if the interest rate differential is not kept constant. In this way, the Norwegian interest rate has more effect on the NOK/euro exchange rate, than the European interest rate in the short run.

The Norwegian interest rate effect is at odds with the result by Bjørnstad and Jansen, who found that an interest rate change in the euro zone has a larger impact on the exchange rate than an interest rate increase of equal size in Norway. Such a finding might be caused by the samples used. Bjørnstad and Jansen use a sample including both fixed exchange rate regimes and floating exchange rates regimes with a stable exchange rate target. Under these regimes, the Norwegian interest rate is dictated by the foreign interest rate. Thus, it is not strange that foreign interest rates have a major impact on the exchange rate. Under a floating exchange rate regime, the fixed relationship between foreign and home interest rates are removed, therefore it might actually be that the Norwegian interest rates has most effect on the exchange rate. I found that the long run impact of a permanent decrease in the interest rate differential is a depreciation of the NOK/euro exchange rate of 10.2%. Bjørnstad and Jansen found the same effect to be equal to 7.9%. The difference might again be due to the sample difference.

5.2.2 The Effect of Prices

I found no evidence that changes in foreign or domestic prices have an immediate impact on the exchange rate. However, in a longer horizon prices have an impact through the real exchange rate relationship. The real exchange rate is an equilibrium variable, which acts as an error corrector. Changes in the long run real exchange rate relationship will have an impact on today's exchange rate, in such a way that the relationship can be back in an equilibrium. According to my model, a 1% change in the real exchange rate will affect the nominal exchange rate with -0.38%.

In my model, I found the oil price not to be significant. The oil price effect on the exchange rate has been discussed in numerous studies. Bjørnland and Hungnes (2003) found the oil price to be insignificant. In addition, Bjørnstad and Jansen found the oil price to only be significant at 5% level, while Akram, in his study "Oil price and exchange rates: Norwegian evidence", found the oil price to have stronger effect if the oil price fell below 15 USD per barrel (Bjørnstad and Jansen (2007). In the portfolio theory the oil price is only involved through the expectations. What the investors base their expectations on is not necessarily constant over time. In my sample (2001(2)-2008(2)) this effect may not have been a dominating one. Even though the increase in oil price in the beginning of 2008 was driven by expectations alone, the resulting oil price effect can have been dominated by the safe haven effect in the determination of exchange rates.

The insignificance of the oil price might on the other hand be a result of the strategy of the Government Pension Fund. All petroleum revenues are transferred to the fund and invested abroad to avoid an overheating in the Norwegian economy and not expose it to the effects of oil price fluctuations. The Norwegian economy might be more dependent on the expected return on the fund through the spending rule, than on the oil price directly.

The oil price can also affect the exchange rate through the flow approach. Nonetheless, the sub sample of my estimation may have been too short to capture this effect.

5.2.3 Explanation of the Development in the NOK/Euro Exchange Rate.

From May 2000 to January 2003, the NOK appreciated considerably. Many reasons for this have been mentioned in the literature, but the dominating ones are increased interest rates relative to other countries, increased oil price, huge surpluses on the current account and the Krones status as a safe haven during unrests in the middle-east, (Naug (2003), Bjørnstad and Jansen (2007), NOU (2003, no13)).

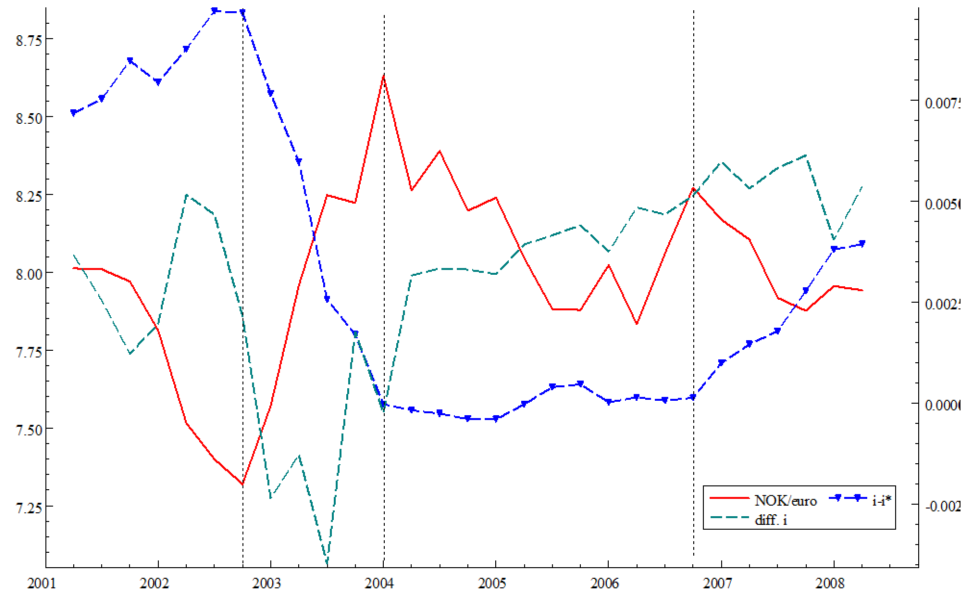

Figure 9, Data plots of the development of the NOK/euro exchange rate (solid line, left axis), the interest rate differential (solid line with dots, right axis) and the change in Norwegian interest rate (dashed line, right axis).

Applying my model and sample from second quarter of 2001 up to second quarter of 2008, I can try to give an explanation of the development in the exchange rate. As we see from Figure 9, the movements in the NOK/euro exchange rate match the movements in the interest rates differential. Up to 2003 the interest rate differential between Norway and Europe increased, which resulted in an appreciation in the exchange rate. After a break point in the last quarter of 2002, the opposite happened. The interest rate differential decreased until it became zero in 2004. The exchange rate moved accordingly.

If the interest rate differential was the only explanatory factor, the exchange rate would be almost stable from 2004 up to 2007 and appreciate after. That did not happen. From 2004 to 2006, the exchange rate appreciated. Several causes operating at more or less the same time can explain this appreciation. Steadily increasing interest rate in Norway, but in accord with the European interest rate, steadily increasing oil price and big surpluses on the current account could have given expectations about a stronger Norwegian currency. These effects might have been captured by the change in the interest rate variable (Δi_t) in my model, since the sub sample might have been to short to discover each effect.

From 2006 to 2007 the exchange rate depreciated. In the same period the change in the Norwegian interest rate was negative, which may explain some of the depreciation. In retrospect, some of this depreciation in the exchange rate has been explained by the decrease in the oil price and the effect this gave on the expected depreciation rate and thus on the risk premium. The decreased risk premium lowered the demand for NOK, and the exchange rate depreciated, (Alendal (2010)). The oil price is not significant in my model, so I cannot check for this effect.

From 2007 up to 2008 it again seems like the interest rate differential was the cause of the appreciation.

5.3 The Failure in Explaining the Financial Crisis.

When I increase the sample size to second quarter of 2009 to include the financial crisis, the significance of the misspecification tests increase dramatically. Both the normality and heteroscedasticity tests become significant at 1% level, in similarity with what happened with the Bjørnstad and Jansen model. This implies that when including the effects that took place during the financial crisis, the relationship between the variables breaks down. The error terms are then left both with non normal distribution and are heteroscedastic. Such a collapse might be due to an omitted variable. Effects that was not very dominant in the exchange rate determination before the financial crisis can have changed to be very dominant during the financial crisis. I expect this to be the effect of the expectations and the role of safe havens, which is not satisfactory included in the model.

This can also be shown in the recursive estimates and the Chow test in Figure 11 in appendix C. As we see in the Chow test in the bottom panel, a structural break occurs in the end of 2008. Furthermore, we observe a reaction to the financial crises in the end of 2008 in all the other recursive estimates. The events that determined the exchange rate during the financial crisis are exceptional circumstances for the time period I look at, which make the relationship between the variables to break down.

5.4 Out of Sample Forecasting

I want to check how the different models perform on forecasts. The models are estimated on data from 2001(2) to 2007 (2). I also include the Random Walk model and the model by Bjørnstad and Jansen as benchmarks.

A graphic representation of the different forecasts is given in Figure 10. An important feature of model (7) is that it not only estimates but also predicts the exchange rate in all periods to be stronger than it actually is. This might be because of the oil price. Although the oil price is insignificant, I have kept it in my model for information purposes, but the wrong sign may create the bias. On the other hand, it might be caused by the interest rate differential. The regression results from 2001 to 2007 might have given the interest rate differential too much weight, since the estimation sample from 2001 to 2004 contains a high interest rate differential. Further on, we can establish that the model estimate the exchange rate to appreciate more than the actual level already from the third quarter of 2006, when the interest rate differential started to increase.

If we disregard the level of the exchange rate, the movement of model (7) is quite well. Although the model lies well over a quarter behind, the movement in (7) follows the actual exchange rate closely. The relationship holds surprisingly well during the financial crisis. Unfortunately, because of the under predictions in the level, the error in the fourth quarter of 2008 is huge.

When it comes to massive shocks to the system, like the financial crisis, the Random Walk model do actually have a great advantage. The true, and so far undiscovered, model of exchange rate determination might be huge and complicated. The advantage of the Random Walk model is that it includes the “true” model only one period late, see chapter 4.4. Econometric models containing equilibrium and error correcting variables will have an ability to explain more of the movements. However, models with economic interpretation can be more vulnerable for structural breaks. When it comes to forecasting, large shocks can change variables in the forecasting period. A Random Walk model will be back on track the next period. Economic models will have to lean on its equilibrium relationship and, thus, adjust more slowly or maybe not adjust at all. This means that models which may not be very well specified, can by luck, do better in forecasts than more correctly specified economic models.

As we see in Table 7 , there are huge differences between the models on forecasting performance considering the RMSE. The Random Walk model is still the best performing model on forecasting. Model (7) performs better than Bjørnstad and Jansen on forecasts up to the financial crisis. When including the financial crisis in the forecast, the RMSE of model (7) increase. I expect this to be a result of the major forecast error in 2008(4). The next step in effort to improve exchange rate forecasting might be to make a forecast on a model made on an average of either Random Walk and Bjørnstad and Jansen or a model based on all three models discussed here. For more discussion about forecast performance of the Bjørnstad and Jansen model and the Random Walk model, see chapter 4.4.

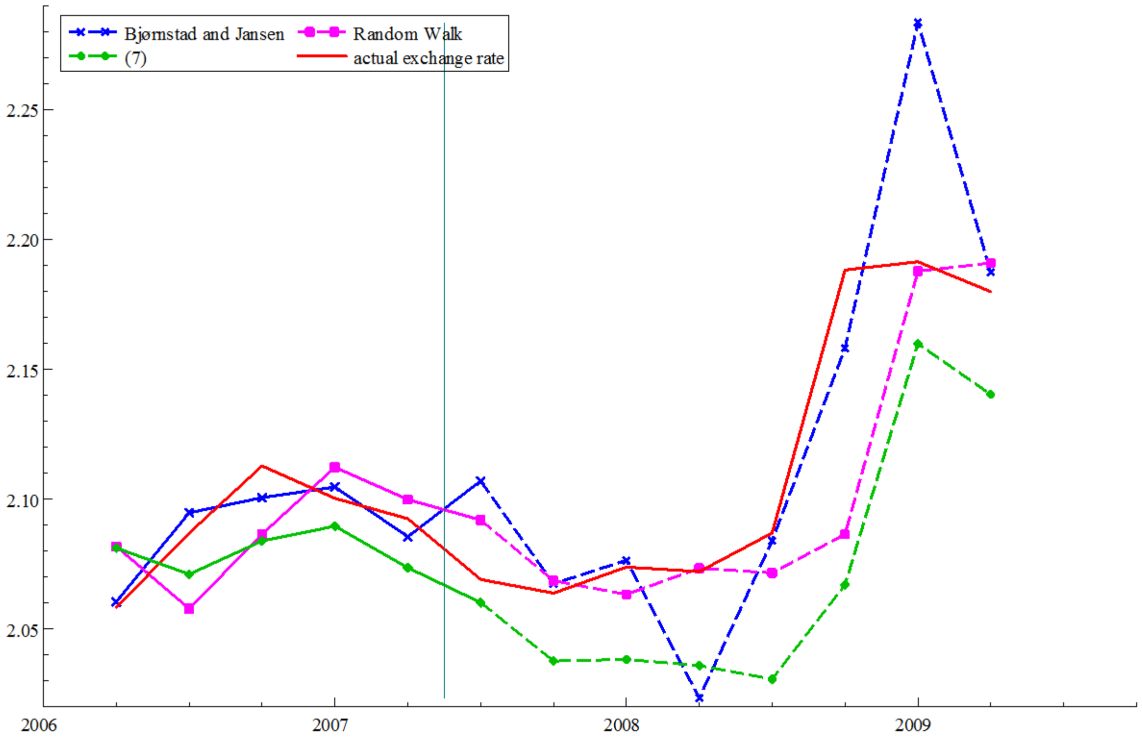

Figure 10 1-Step Ahead forecasts from 2007(2)-2009(2) for the model by Bjørnstad and Jansen, Random Walk and model (7).

Table 7 RMSE from 1-Step Ahead forecasts, when estimating from 2001(2)-2007(2). (RMSE*100)

Forecast period	Bjørnstad and Jansen	Random Walk	(7)
$\mathbf{RMSE_{2007(3)-2008(2)}}$	3.09	1.28	2.89
$\mathbf{RMSE_{2007(3)-2009(2)}}$	4.07	3.77	5.45

6 Conclusion

The main finding of this thesis is that interest rates are major explanatory variables for exchange rates under inflation targeting. In the case of NOK/Euro exchange rate, the interest rate differential and a change in the Norwegian interest rate in particular has the biggest impact on the exchange rate.

When it comes to explaining the exchange rate during the financial crisis, my model breaks down and shows signs of omitted variables. I attribute this to the role of expectations and feeling of security, that safe havens give during unrest in the financial markets. Speculators, who ran to big currencies during the financial crisis, had huge impact on the exchange rate of currencies that cannot be explained by the fundamentals.

In forecasting the financial crisis, none of the econometric models could beat a simple Random Walk. A model which may not be as good in explaining the exchange rate, can still be best on forecasting in periods with great uncertainty. The next step in the forecast competition against the Random Walk would be to make a model which contains the level of the forecast by Bjørnstad and Jansen, and the movements of model (7). In other words, make an average of the Bjørnstad and Jansen model and model (7) and compare against a Random Walk model.

Unfortunately, the inflation target period in Norway has only lasted for 9 years, and two of these years contain the financial crisis. A short time span, as the one in question, implies that the data sample is very small and do not give an opportunity to extensive testing. More observations under “normal times” might have given cleaner results. An interesting thing to do when the time comes is to check if models can perform forecast or estimate the new equilibrium exchange rate after the financial crisis.

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Register of Tables and Figures

Attachments

A: Data appendix

Variable definitions
The original data set (as in Bjørnland and Hungnes (2006) and Bjørnstad and Jansen (2007))
v_t= log of the nominal exchange rate between NOK/euro. Before the introduction of euro (January 1st 1999), theoretical ECU is used.
p_t= log of the domestic price (CPI, Norway).
p_t^*= log of the foreign price (euro area CPIs). Last quarter (2009q2) is calculated from preliminary numbers from the European central bank ECB)
i_t= domestic interest rate (3 month money market rates, Norway).
i_t^*= foreign interest rate (3 month money market rates, euro area).
p_t^{oil}= (log of) price of Brent crude oil (USD/barrel). Data including 2007q4 are from Norges Bank data bank. From 2008q1data are from Ecowins corresponding series. The discrepancy between the two series is around 50 cents per barrel of oil in the period | they can be compared (in 2008q1 nearly identical)[23]
p_t^{jae} (Log of) consumer price index, net of energy prices and excises (Norway).
Δ=difference operator, i.e. $\Delta v_t = v_t - v_{t-1}$
$i_t - \Delta p_t$ =Real interest rates, Norway.
$i_t^* - \Delta p_t^*$ =Real interest rates, euro area.
$STEP_{2001q2} = 0$ Up to and including 2001q1 (i.e. exchange rate targeting regime
$STEP_{2001q2} = 1$ After 2001q1 (i.e. inflation targeting regime)
$Dxxqy = 1$In 19xx or 20xx, quarter y, and 0 otherwise

[23] E.Jansen, in mail received 25.1.2010

B: The supply curve.

The equations:

1) $W_p = \frac{B_p + EF_p}{P}$

2) $W_* = \frac{\frac{B_*}{E} + F_*}{P_*}$

3) $r = i - i_* - e_e$

4) $e_e = e_e(E)$

5) $\frac{EF_P}{P} = f(r, W_p)$

6) $\frac{F_*}{P_*} = W_* - b(r, W_*)$

7) $F_g + F_p + F_* = 0$

Set equation 7 into equation 5: $\frac{E(-F_* - F_g)}{P} = f(r, W_p)$

Solve for F_*: $F_* = -\frac{P}{E} f(r, W_p) - F_g$

Insert into equation 6: $\frac{-\frac{P}{E} f(r, W_p) - F_g}{P_*} = W_* - b(r, W_*)$

Solve for F_g: $F_g = -P_* W_* + P_* b(r, W_*) - \frac{P}{E} f(r, W_p)$

Insert equation 1, 2, 3 and 4:

$$F_g = -P_* \frac{\frac{B_*}{E} + F_*}{P_*}_* + P_* b\left(i - i_* - e_e(E), \frac{\frac{B_*}{E} + F_*}{P_*}\right) - \frac{P}{E} f\left(i - i_* - e_e(E), \frac{B_p + EF_p}{P}\right)$$

$$= -\frac{P}{E} f\left(i - i_* - e_e(E), \frac{B_p + EF_p}{P}\right) - P_*[\frac{\frac{B_*}{E} + F_*}{P_*} - b(i - i_* - e_e(E), \frac{\frac{B_*}{E} + F_*}{P_*})] = F^s(E, i - i_*)$$

C: Tables and Figures

Table 8: Correlation matrix from PcGive.

	Δv_t	Δv_{t-1}	α	Δp^*_{t-2}	v_{t-1}
Δv_t	1.0000	0.044891	0.00000	-0.086505	-0.35012
Δv_{t-1}	0.044891	1.0000	0.00000	0.19790	0.34128
α	0.00000	0.00000	0.00000	0.00000	0.00000
Δp^*_{t-2}	-0.086505	0.19790	0.00000	1.0000	-0.018306
v_{t-1}	-0.35012	0.34128	0.00000	-0.018306	1.0000
p_{t-1}	0.16816	0.070693	0.00000	0.016045	0.14390
p^*_{t-1}	0.071956	-0.021787	0.00000	0.045226	0.18183
i_t	-0.17575	-0.21536	0.00000	0.095412	-0.52812
i_{t-1}	-0.020168	-0.12552	0.00000	0.066325	-0.59028
i^*_t	-0.21014	-0.15741	0.00000	0.10382	-0.13981
p^{oil}_t	-0.015985	-0.094402	0.00000	0.048162	0.16902
Δi_t	-0.57543	-0.32330	0.00000	0.10264	0.27711
$(v-p+p^*)_{t-1}$	-0.35367	0.21399	0.00000	0.020489	0.94074
i_t-i^*_t	-0.10695	-0.19666	0.00000	0.064785	-0.64357

	p_{t-1}	p^*_{t-1}	i_t	i_{t-1}	i^*_t
Δv_t	0.16816	0.071956	-0.17575	-0.020168	-0.21014
Δv_{t-1}	0.070693	-0.021787	-0.21536	-0.12552	-0.15741
α	0.00000	0.00000	0.00000	0.00000	0.00000
Δp^*_{t-2}	0.016045	0.045226	0.095412	0.066325	0.10382
v_{t-1}	0.14390	0.18183	-0.52812	-0.59028	-0.13981
p_{t-1}	1.0000	0.97994	-0.30557	-0.42552	0.27563
p^*_{t-1}	0.97994	1.0000	-0.33208	-0.47071	0.26575
i_t	-0.30557	-0.33208	1.0000	0.96463	0.74943
i_{t-1}	-0.42552	-0.47071	**0.96463**	1.0000	0.60385
i^*_t	0.27563	0.26575	0.74943	0.60385	1.0000
p^{oil}_t	0.94048	0.96628	-0.27433	-0.42986	0.32759
Δi_t	0.47846	0.55132	0.055047	**-0.21011**	0.49226
$(v-p+p^*)_{t-1}$	0.39899	0.46873	-0.57203	-0.68107	-0.048550
i_t-i^*_t	-0.60600	-0.63642	0.90098	**0.94714**	0.38797

	p^{oil}_t	Δi_t	$(v-p+p^*)_{t-1}$	i_t-i^*_t
Δv_t	-0.01598	-0.57543	-0.35367	-0.10695
Δv_{t-1}	-0.094402	-0.32330	0.21399	-0.19666
α	0.00000	0.00000	0.00000	0.00000
Δp^*_{t-2}	0.048162	0.10264	0.020489	0.064785
v_{t-1}	0.16902	0.27711	0.94074	-0.64357
p_{t-1}	0.94048	0.47846	0.39899	-0.60600
p^*_{t-1}	0.96628	0.55132	0.46873	-0.63642

i_t	-0.27433	0.055047	-0.57203	0.90098
i_{t-1}	-0.42986	-0.21011	-0.68107	0.94714
i_t^*	0.32759	0.49226	-0.048550	0.38797
p_t^{oil}	1.0000	0.61074	0.45220	-0.59656
Δi_t	0.61074	1.0000	0.45816	-0.24594
$(v-p+p^*)_{t-1}$	0.45220	0.45816	1.0000	-0.76450
i_t-i_t^*	-0.59656	-0.24594	-0.76450	1.0000

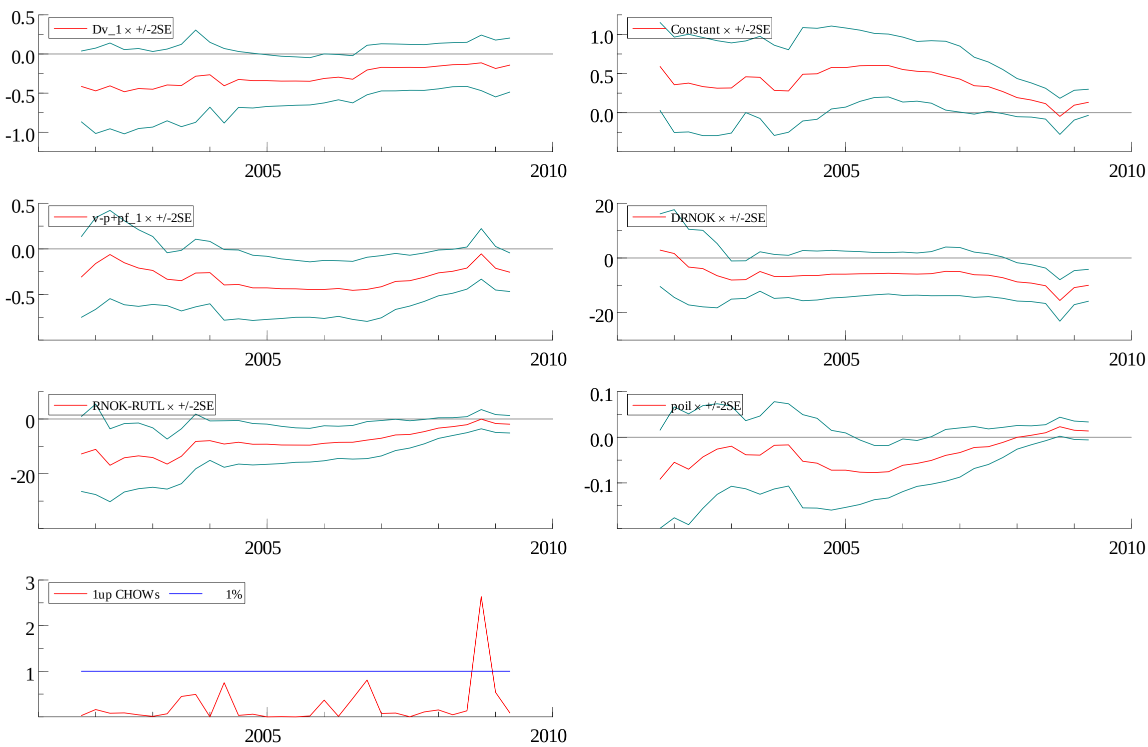

Figure 11 recursive estimates of the coefficients (±2 standard errors) in the exchange rate model (7) on the sub sample 2001q2 -2009q2

D: variance of forecast errors

Dynamic programming for Random Walk.

$$v_t = \alpha + v_{t-1} + u_t$$

Forecasts for t+1, t+2, ..., t+N :

$$\hat{v}_{t+1} = \alpha + v_t$$

$$\hat{v}_{t+2} = \alpha + \hat{v}_{t+1} = 2\alpha + v_t$$

$$\hat{v}_{t+N} = N\alpha + v_t$$

True value for t+1, t+2 , ..., t+N :

$$v_{t+1} = \alpha + v_t + u_{t+1}$$

$$v_{t+N} = N\alpha + v_t + \sum_{j=1}^{N} u_{t+j}$$

Forecast error:

$$v_{t+N} - \hat{v}_{t+N} = \sum_{j=1}^{N} u_{t+j}$$

Variance of forecast error:

$$var(v_{t+N} - \hat{v}_{t+N}) = var\left(\sum_{j=1}^{N} u_{t+j}\right) = N\sigma_u^2$$

<u>The variance of the forecast error ($N\sigma_u^2$) increase as N increase.</u>

Dynamic programming for conditional model (Bjørnstad and Jansen).

$$v_t = \alpha + \beta v_{t-1} + \gamma X_t + u_t$$

Assume a stable solution: 0<β<1

Forecasts for t+1, t+2, ..., t+N :

$$\hat{v}_{t+1} = \alpha + \beta v_t + \gamma X_{t+1}$$

$$\hat{v}_{t+2} = \alpha + \beta\hat{v}_{t+1} + \gamma X_{t+2}$$

$$= \alpha + \beta(\alpha + \beta v_t + \gamma X_{t+1}) + \gamma X_{t+2}$$

$$= \alpha(1+\beta) + \beta^2 v_t + \beta\gamma X_{t+1} + \gamma X_{t+2}$$

$$\hat{v}_{t+N} = \alpha\sum_{i=0}^{N}\beta^i + \beta^N v_t + \beta^{N-1}\gamma X_{t+1} + \beta^{N-2}\gamma X_{t+2} + \cdots$$

True value for t+1, t+2, ..., t+N :

$$v_{t+1} = \alpha + \beta v_t + \gamma X_{t+1} + u_{t+1}$$

$$v_{t+2} = \alpha + \beta v_{t+1} + \gamma X_{t+2} + u_{t+2}$$

$$= \alpha + \beta(\alpha + \beta v_t + \gamma X_{t+1} + u_{t+1}) + \gamma X_{t+2} + u_{t+2}$$

$$= \alpha(1+\beta) + \beta^2 v_t + \beta\gamma X_{t+1} + \gamma X_{t+2} + \beta u_{t+1} + u_{t+2}$$

$$v_{t+N} = \alpha\sum_{i=0}^{N}\beta^i + \beta^N v_t + \beta^{N-1}\gamma X_{t+1} + \beta^{N-2}\gamma X_{t+2} + \cdots + u_{t+N} + \beta u_{t+N-1} + \beta^2 u_{t+N-2} + \cdots$$

Forecast error:

$$v_{t+N} - \hat{v}_{t+N} = u_{t+N} + \beta u_{t+N-1} + \beta^2 u_{t+N-2} + \cdots$$

Variance of forecast error:

$$var(v_{t+N} - \hat{v}_{t+N}) = var(u_{t+N} + \beta u_{t+N-1} + \beta^2 u_{t+N-2} + \cdots)$$

$$= \frac{\sigma_u^2}{1-\beta}$$

<u>The variance of the forecast error converges towards a constant ($\frac{\sigma_u^2}{1-\beta}$) as N increase</u>.

PcGive output

Random Walk

Dynamic (ex ante) forecasts for v (SE based on error variance only)

Horizon	Forecast	SE	Actual	Error	t-value
2006-4	2.08823	0.01856	2.11278	0.0245476	1.322
2007-1	2.08949	0.02625	2.10034	0.0108528	0.413
2007-2	2.09075	0.03215	2.09246	0.00170333	0.053
2007-3	2.09202	0.03712	2.06908	-0.0229363	-0.618
2007-4	2.09328	0.04151	2.06383	-0.0294504	-0.710
2008-1	2.09454	0.04547	2.07386	-0.0206761	-0.455
2008-2	2.09580	0.04911	2.07213	-0.0236764	-0.482
2008-3	2.09706	0.05250	2.08696	-0.0101048	-0.192
2008-4	2.09833	0.05569	2.18819	0.0898647	1.614
2009-1	2.09959	0.05870	2.19134	0.0917540	1.563
2009-2	2.10085	0.06156	2.17983	0.0789838	1.283

mean(Error) = 0.017351 RMSE = 0.048561
SD(Error) = 0.045355 MAPE = 1.7124

Bjørnstad and Jansen
Dynamic (ex ante) forecasts for v (SE based on error variance only)

Horizon	Forecast	SE	Actual	Error	t-value
2006-4	2.08374	0.008545	2.11278	0.0290364	3.398
2007-1	2.09281	0.01019	2.10034	0.00753255	0.739
2007-2	2.06450	0.01081	2.09246	0.0279563	2.587
2007-3	2.06672	0.01168	2.06908	0.00235547	0.202
2007-4	2.05349	0.01242	2.06383	0.0103394	0.832
2008-1	2.05213	0.01294	2.07386	0.0217350	1.679
2008-2	2.00256	0.01339	2.07213	0.0695652	5.194
2008-3	2.00822	0.01379	2.08696	0.0787396	5.711
2008-4	2.05283	0.01411	2.18819	0.135363	9.591
2009-1	2.14285	0.01439	2.19134	0.0484951	3.370
2009-2	2.09267	0.01463	2.17983	0.0871600	5.960

mean(Error) = 0.047116 RMSE = 0.061480
SD(Error) = 0.039495 MAPE = 2.2054